1527 Cole Boulevard, Suite 300
Denver, CO 80401

T: 303.239.5400
F: 303.239.5454

Technical Memorandum

Prepared for: Homestake Mining Company of California

Project title: Groundwater Flow Modeling Support

Project no.: 150952.001

Technical Memorandum

Subject: San Mateo Creek Basin and HMC Mill Hydrogeologic Site Conceptual Models

Date: January 8, 2018

To: Tom Wohlford, Closure Manager

From: Jeff Weaver

Copy to: Chuck Zimmerman

Prepared by: ______________________
Jeff Weaver, Senior Expert, Hydrogeology

Prepared by: ______________________
Carter Coolidge, Senior Professional, Hydrogeology

Reviewed by: ______________________
Kurt Zeiler, Expert, Hydrogeology

Limitations:

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ac-ft	acre-foot/feet
amsl	above mean sea level
BC	Brown and Caldwell
d	day(s)
ft	foot/feet
ft^2	square foot/feet
gpm	gallon(s) per minute
HMC	Homestake Mining Company
HSCM	hydrogeologic site conceptual model
L	liter(s)
mg	milligram(s)
NMONRT	New Mexico Office of Natural Resources Trustees
Regional HSCM	hydrogeologic site conceptual model for the surrounding San Mateo Creek groundwater basin
SAG	San Andres/Glorieta
Site HSCM	hydrogeologic site conceptual model for the Homestake Mining Company Mill Site
SMC	San Mateo Creek
TDS	total dissolved solids
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Executive Summary

Brown and Caldwell (BC) has prepared hydrogeologic site conceptual models (HSCMs) for the Homestake Mining Company of California (HMC) Mill Site (Site HSCM) and the surrounding San Mateo Creek (SMC) groundwater basin (Regional HSCM) near Grants, New Mexico. This technical memorandum is the culmination of our review of background information related to local and regional geology, hydrogeology, water quality, ongoing remediation activities, and regulatory issues at the HMC Mill site and other sites in the SMC Basin.

The general objective of BC's Phase I background review is to develop both site-specific and regional HSCMs that will form the framework for development of numerical groundwater flow and contaminant transport models covering both regional and site scales. An HSCM is a summary of available knowledge related to groundwater flow and water quality of the principal hydrostratigraphic units at a certain location and scale. The Site and Regional HCSMs describe the current understanding of the following:

- Geologic conditions affecting groundwater flow and water quality, including the influence of geologic structures (e.g., faulting)
- Identification of principal hydrostratigraphic units and aquifers
- Locations and mechanisms of recharge of water to and discharge from principal hydrostratigraphic units and aquifers
- Groundwater flow directions and hydraulic gradients
- Physical properties of hydrostratigraphic units and aquifers, including transmissivity, hydraulic conductivity, and groundwater storage
- Potential for flow interactions between hydrostratigraphic units and aquifers
- Anthropogenic influences on principal hydrostratigraphic units and aquifers (extraction, injection, and water quality impacts) over time

The HMC Mill site is located about 6 miles north of Grants in the southern (lower) SMC Basin. The SMC Basin includes the Grants Mineral Belt, which produced more uranium than any other district in the world during the period 1951–80. There are more than 85 legacy mining and mill sites in the SMC Basin and mining and remediation activities have had a significant impact on local and regional groundwater flow conditions and water quality.

Significant remedial activities have occurred in the following four uranium mill sites in the SMC Basin:

- HMC Mill site
- Bluewater Mill site, about 7 miles to the west of the HMC
- Rio Algom/Quivira Mill site (also referred to as the Ambrosia Lake Mill site) in the northern (upper) SMC Basin
- Phillips Mill site, also in the Ambrosia Lake area

Regionally, the SMC Basin is located in the southeastern portion of the Colorado Plateau physiographic province on the south flank of the San Juan Basin. The region experienced structural deformation during the Laramide Orogeny from near the end of the Late Cretaceous through the Eocene. Uplift associated with this orogeny formed the Zuni Mountains to the southwest of the SMC Basin, which consists of a northwest-trending monoclinal fold dipping northeast into the San Juan Basin. The SMC Basin lies on the eastern flank of the fold, resulting in bedrock and strata that dip to the north-northeast at about 5 to 10 degrees into the San Juan Basin.

The primary regional aquifer units in the San Juan Basin, which include groundwater flow originating in the SMC Basin, are as follows (from youngest to oldest):

- Quaternary valley fill deposits (alluvium)
- Menefee Formation
- Point Lookout Sandstone
- Crevasse Canyon Formation
- Gallup Sandstone
- Dakota Sandstone
- Morrison Formation
- Bluff Sandstone
- Entrada Sandstone
- San Andres/Glorieta (SAG) aquifer

The Morrison Formation, Entrada Complex, and SAG are considered the major aquifers in the SMC Basin.

The SMC Basin is primarily a region of recharge to groundwater, both to shallow and deeper hydrostratigraphic units. Groundwater recharge, discharge, and flow characteristics as well as aquifer physical properties for each of the principal aquifers in the SMC Basin are provided as part of the Regional HSCM. The effects of groundwater extraction in the alluvial, Morrison Formation, and SAG aquifer on regional flow conditions are presented. The main structural features in the SMC Basin consist of north- to northeast-trending subvertical normal faults, which may locally either impede or facilitate groundwater flow, depending on orientation and offset.

Locally at the HMC Mill site, uranium ore from the Grants Mineral Belt was processed at the site from 1958–90 (HDR 2016). The site currently consists of partially reclaimed tailings piles, buried (i.e., reclaimed) mill debris, and wells and evaporation ponds related to ongoing active groundwater restoration.

The following four geologic units are present at the HMC Mill site:

- Alluvium
- Chinle Formation
- San Andres Limestone
- Glorieta Sandstone

Quaternary alluvium underlies the entire site, has variable hydraulic characteristics, and is generally 50 to 100 feet thick.

The Chinle Formation is up to 900 feet thick at the site. Although the Chinle is dominated by low-permeability shale units, beneath the site it contains three water-bearing units of relatively higher permeability. These water-bearing units are referred to as the Upper Chinle Sandstone, Middle Chinle Sandstone, and Lower Chinle Mudstone.

The lowermost units of interest at the site are the San Andres Limestone and Glorieta Sandstone, which together are 200 to 225 feet thick. The SAG is overlain by an unconformity and underlain by the lower-permeability Yeso and Abo formations.

The sedimentary rock units at the site dip gently to the east-northeast, following the regional dip of these units. Pre-Quaternary deformation and erosion has resulted in sedimentary rock units that subcrop beneath the alluvium at the site.

Two north-northeast-trending normal faults are present at the site, known as the East Fault and West Fault. These faults are approximately vertical and down-dropped on the east. The vertical displacements of the faults have juxtaposed the more permeable units of the Chinle Formation against less permeable mudstone layers, thus affecting the local flow regime. The San Andres Limestone and Glorieta Sandstone, although vertically displaced, maintain horizontal connectivity across the faults and flow is not affected.

The primary sources of groundwater contamination at the HMC Mill site are the Large and Small tailings piles. Historical seepage of process-water-bearing uranium and other trace radioactive and non-radioactive constituents resulted in loading of metals to alluvial groundwater beneath the tailings piles. Contamination has since migrated to the Upper, Middle, and Lower Chinle water-bearing zones. Groundwater contamination from the HMC Mill site has not been detected in the SAG aquifer. Substantial progress in reducing constituent concentrations has been made in the alluvial and Chinle water-bearing zones since remediation activities began in the 1980s.

The descriptions of the Regional and Site HSCMs provided here are the culmination of BC's review of available background information related to local and regional geology and hydrogeology in the SMC Basin. The data and descriptions of geologic conditions, principal aquifer units, locations and mechanisms of groundwater recharge and discharge, groundwater flow directions and hydraulic gradients, and aquifer physical parameters will form the basis for numerical model development at both the regional and site scales. BC will provide a detailed plan for numerical model development as part of the next phase of support for developing flow and transport models for the SMC Basin and the HMC Mill site.

Section 1: Introduction

Brown and Caldwell (BC) is pleased to present two hydrogeologic site conceptual models (HSCMs) for the Homestake Mining Company of California (HMC) Mill Site (Site HSCM) and the surrounding San Mateo Creek (SMC) groundwater basin (Regional HSCM) near Grants, New Mexico. This technical memorandum is the culmination of our review of background information related to local and regional geology, hydrogeology, water quality, ongoing remediation activities, and regulatory issues at the HMC Mill site and other sites in the SMC Basin. The scope of BC's review of background information (Phase I) was described in our Scope of Work and Cost Estimate: Groundwater Modeling Activities (letter dated June 8, 2017).

The general objective of BC's Phase I background review is to develop both site-specific and regional HSCMs that will form the framework for development of numerical groundwater flow and contaminant transport models covering both regional and site scales. An HSCM is a summary of available knowledge related to groundwater flow and water quality of the principal hydrostratigraphic units at a certain location and scale. The understanding of the site and region include the following descriptions, with appropriate graphics, tables, and supporting information:

- Geologic conditions affecting groundwater flow and water quality, including the influence of geologic structures (e.g., faulting)
- Identification of principal hydrostratigraphic units and aquifers
- Locations and mechanisms of recharge of water to and discharge from principal hydrostratigraphic units and aquifers
- Groundwater flow directions and hydraulic gradients
- Physical properties of hydrostratigraphic units and aquifers, including transmissivity, hydraulic conductivity, and groundwater storage
- Potential for flow interactions between hydrostratigraphic units and aquifers
- Anthropogenic influences on principal hydrostratigraphic units and aquifers (extraction, injection, and water quality impacts) over time

These elements of the HSCMs will form the basis for numerical model development, including lateral model domain extents, model layer structures, boundary conditions, physical parameterizations, and calibration approaches. The following sections describe the Regional and Site HSCMs based on available data and reports, which are cited in the appropriate sections.

Section 2: Regional Hydrogeologic Site Conceptual Model

The HMC Mill site is located about 6 miles north of Grants in the SMC Basin, which encompasses an area of approximately 321 square miles and is shown by the blue outline on Figure 1 (the scale of which is approximately 1 inch = 10 miles). The SMC Basin includes the Grants Mineral Belt, which produced more uranium than any other district in the world during the period 1951–80 (HDR 2016). There are more than 85 legacy mining and mill sites in the SMC Basin and mining and remediation activities have had a significant impact on local and regional groundwater flow conditions and water quality.

Significant remedial activities have occurred in four uranium mill sites in the SMC Basin, which are shown on Figure 2. The scale of Figure 2 is approximately 1 inch = 4 miles and the location of the HMC Mill site relative to Grants (about 6 miles north), the slight bend in State Highway 605, and the north boundary of Cibola County are useful reference points for subsequent maps in this technical memorandum. These include the HMC Mill site and Bluewater Mill site in the lower (southern) SMC Basin, which is defined as the portion below the confluence of San Mateo and Arroyo del Puerto (Figures 1 and 2). The Rio Algom/Quivira Mill site (also referred to as the Ambrosia Lake Mill site) and the Phillips Mill site in the Ambrosia Lake area are located in the upper (northern) SMC Basin about 12 miles north of the HMC Mill site (Figure 2). Significant groundwater data have been collected at these sites associated with past and ongoing remedial activities, and these data have been used in the development of the Regional HSCM in this section and the Site HSCM in Section 3.

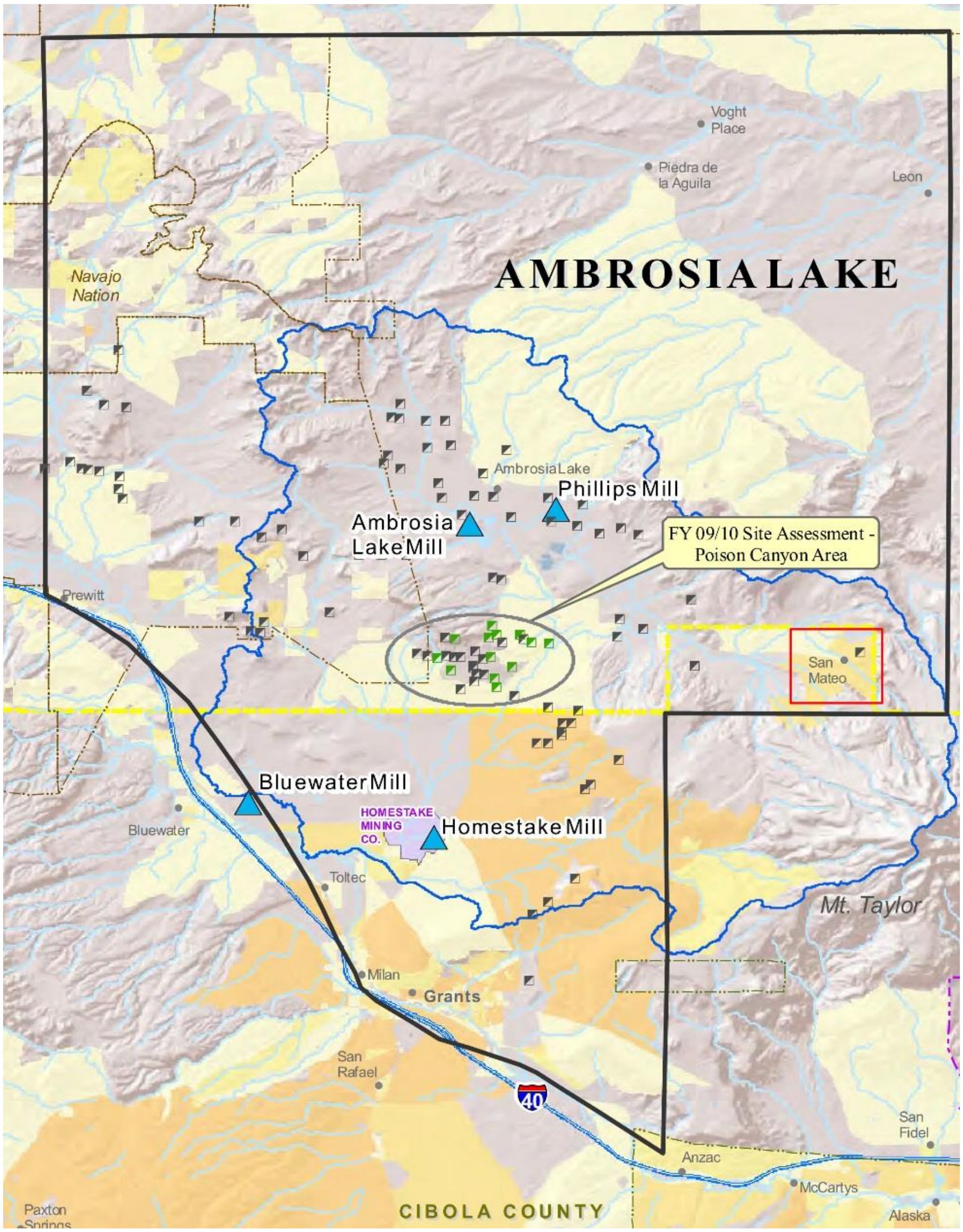


Figure 1. Site Location Map

Source: HDR 2016

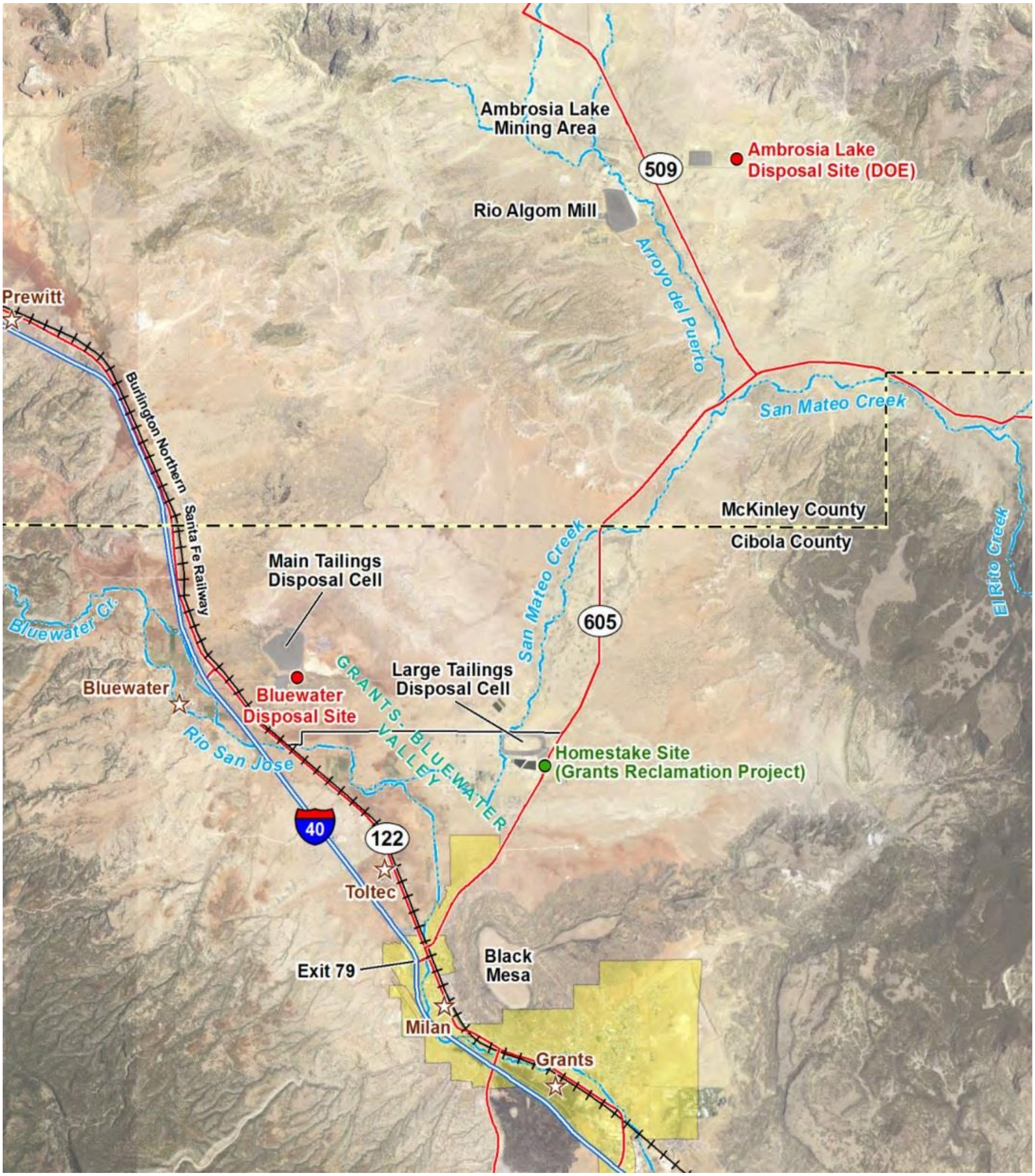


Figure 2. Location of Historical Uranium Milling Operations

Source: U.S. DOE 2014

2.1 Regional Geology

The SMC Basin is located in the southeastern portion of the Colorado Plateau physiographic province on the south flank of the San Juan Basin. The geographic features overlying the San Juan Basin in northwest New Mexico are shown on Figure 3. The San Juan Basin extends from the Chuska Mountains near the Arizona border on the west to the Sierra Nacimiento on the east (Figure 3). The region experienced structural deformation associated with the Zuni Uplift (just south of Grants), which occurred during the Laramide Orogeny from near the end of the Late Cretaceous through the Eocene (HDR 2016). This uplift formed the Zuni Mountains to the southwest of the SMC Basin, which consists of a northwest-trending monoclinal fold approximately 75 miles long and 30 miles wide to the southwest of Grants that exposes Precambrian basement in its core (Langman et al. 2012). The SMC Basin lies on the eastern flank of the fold, resulting in bedrock that dips to the north-northeast at about 5 to 10 degrees into the San Juan Basin.

Surface geology in the SMC Basin includes overlying Tertiary units consisting of widely scattered andesite and basalt flows from volcanic activity associated with the Mount Taylor volcanic field (HDR 2016). An erosional period following the volcanism created the valley forms observed in the SMC Basin, eroding the surface up to 150 to 200 feet below the current land surface (Langman et al. 2012). The valleys subsequently filled with younger Quaternary sediment and additional basalt flows to create the present land surface. Sediment from eroding highlands was deposited in the valleys as unconsolidated alluvium. Figure 4 shows the general extent of alluvium within the SMC Basin.

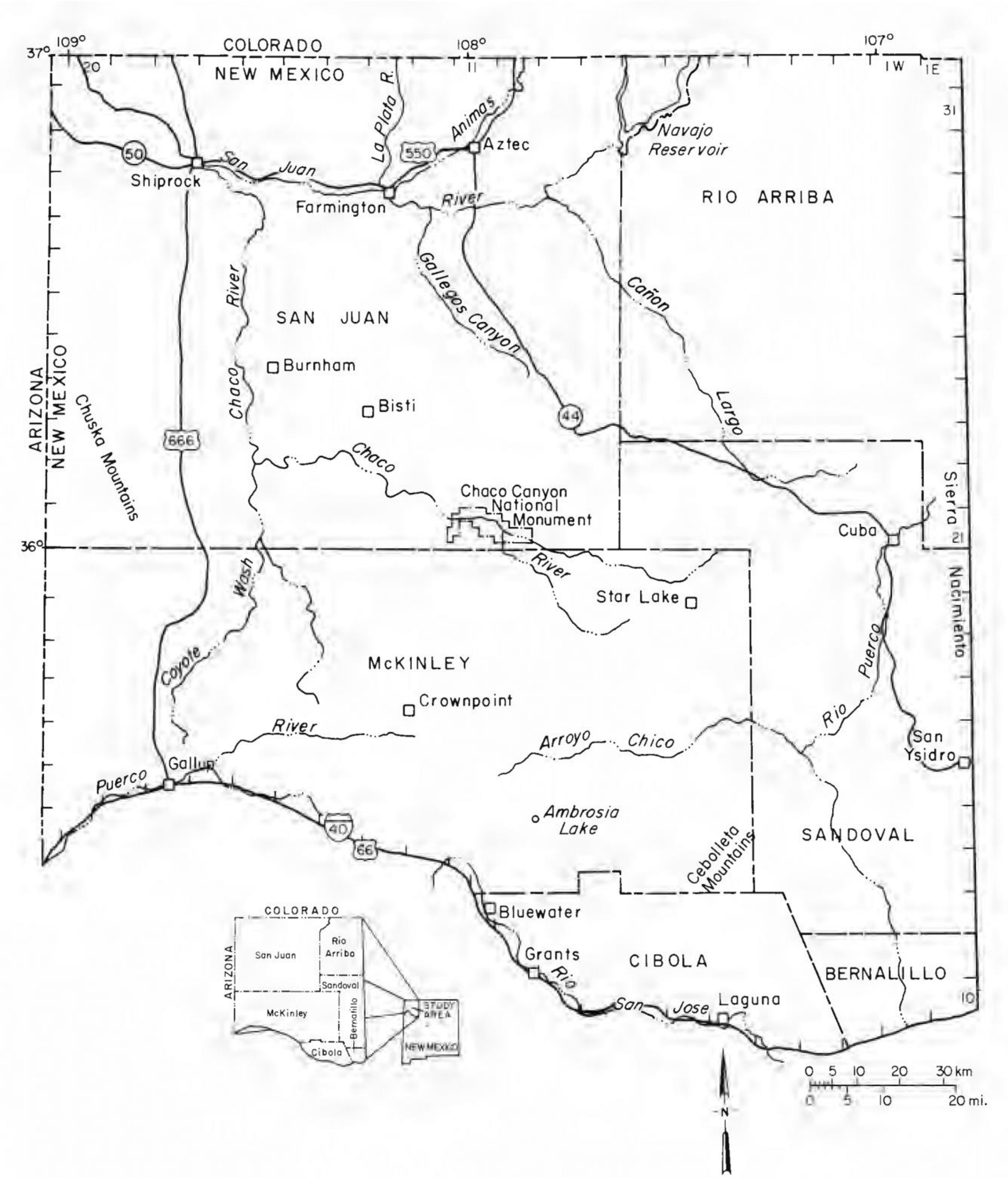


Figure 3. Geography of Northwest New Mexico

Source: Stone et al. 1983

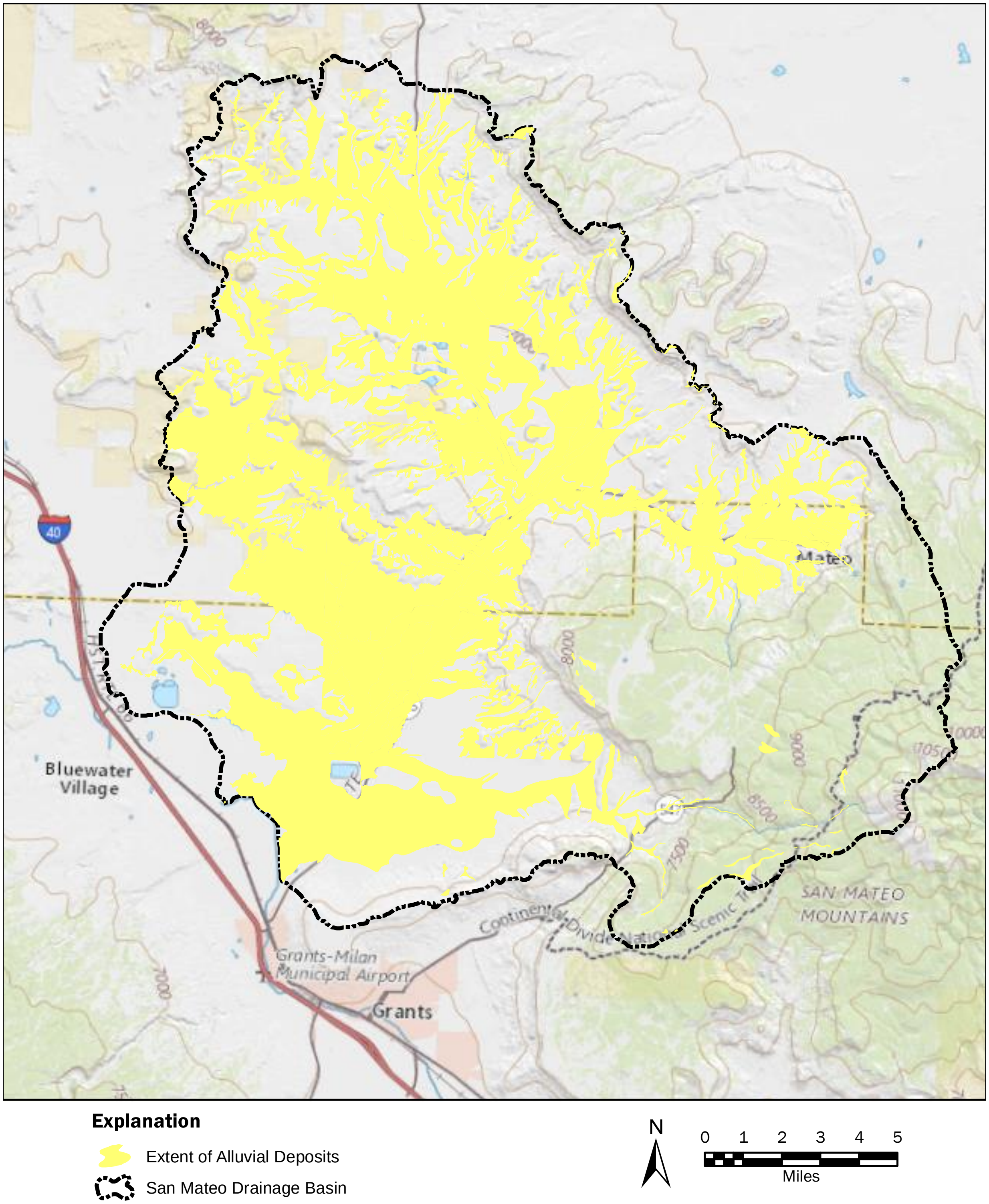


Figure 4. Extent of Alluvial Deposits in the San Mateo Creek Basin

Sources: Cather 2010; Cather 2011; Ferguson and McCraw 2010; Goff et al. 2008; McCraw et al. 2009; Rawling 2012; Rawling 2013a; Rawling 2013b; Zeigler et al. 2012

Subsurface geology in the SMC Basin consists of a thick section of sedimentary units including limestone, sandstone, and shales deposited during the Permian, Triassic, Jurassic, and Cretaceous periods. The primary Paleozoic and Mesozoic sedimentary units (with common map abbreviations) in the basin are summarized as follows from youngest to oldest (McCraw et al. 2009):

- Cretaceous:
  - Menefee Formation (Kmf): interbedded shales, siltstones, fine- to medium-grained sandstones, mudstones, and thin coals
  - Point Lookout Sandstone (Kpl): medium- to fine-grained cross-bedded sandstone
  - Crevasse Canyon Formation (Kc):
    - Gibson Coal Member (Kcg): interbedded siltstone, thin- to medium-bedded sandstone, and black coal
    - Dalton Sandstone Member (Kcd): various sandstones
    - Dilco Coal Member (Kcdc): interbedded siltstones, thin- to medium-bedded sandstones, and black coal
  - Gallup Sandstone (Kg): medium- to thick-bedded, cross-bedded sandstones, including Main (Kgm), Upper (Kgu), and Lower tongues (Kgl)
  - Mancos Shale (Km): shale and silty shale intercalated with finely laminated to cross-bedded thinly bedded sandstone, including:
    - Mulatto Tongue (Kmm): thin-bedded tabular to ripple-laminated sandstone and black shale
  - Dakota Formation (Kd): alternating sandstones and shales
- Jurassic:
  - Morrison Formation (Jm):
    - Brushy Basin Member (Jmb): mudstone interbedded with thin lenticular beds of fine- to medium-grained sandstone
    - Westwater Canyon (Jmw): fine- to medium-grained sandstones interbedded with mudstones
  - San Rafael Group (aka Entrada Complex):
    - Bluff Sandstone (Jb): sandstones
    - Summerville Formation (Js): thin alternating beds of mudstone, siltstone, and sandstone
    - Todilto Limestone (Jt): limestone
    - Entrada Sandstone (Je): a three-member formation consisting of upper and lower sandstones with a middle siltstone
- Triassic:
  - Chinle Group (TRc): mudstone and siltstone with clayey/silty sandstone lenses
- Permian:
  - San Andres (Psa): upper and lower massive fossiliferous limestone separated by sandstone
  - Glorieta (Pg): massive, well-sorted and cemented fine- to medium-grained sandstone
  - Yeso (Py): sandstone, clayey sandstone, and siltstone mixed with carbonates and evaporites
  - Abo (Pa): fine- to coarse-grained sandstone, siltstone, and mudstone with conglomerates in lower unit

Figure 5 shows the surface geology in the SMC Basin, including the Precambrian crystalline basement rocks of the Zuni Uplift. The HMC Mill site is approximately 6 miles north of Grants on State Highway 605. Figure 6 presents a generalized southwest-to-northeast cross section through the basin showing the general relations and relative thicknesses of the sedimentary units described above (note: the section line shown on Figure 5 is not the same as the one on Figure 6).

As noted, the SMC Basin lies at the southern margin of the San Juan Basin (roughly the southern margin of the area shown on Figure 3). Sedimentary units in the SMC Basin dip toward the north-northeast into the main San Juan Basin, as shown on Figure 6. Figure 7 shows a conceptual southwest-northeast geologic cross section that transects the entire San Juan Basin (from Frenzel and Lyford 1982), which illustrates the larger-scale dip of bedrock units toward the center of the basin. In the southwest (SMC Basin), a relatively thin section of Paleozoic strata (the Abo and Yeso formations) is present between the San Andres Limestone and underlying Glorieta Sandstone (collectively referred to as the SAG) and the underlying Precambrian basement that thicken northeast toward the center of the San Juan Basin.

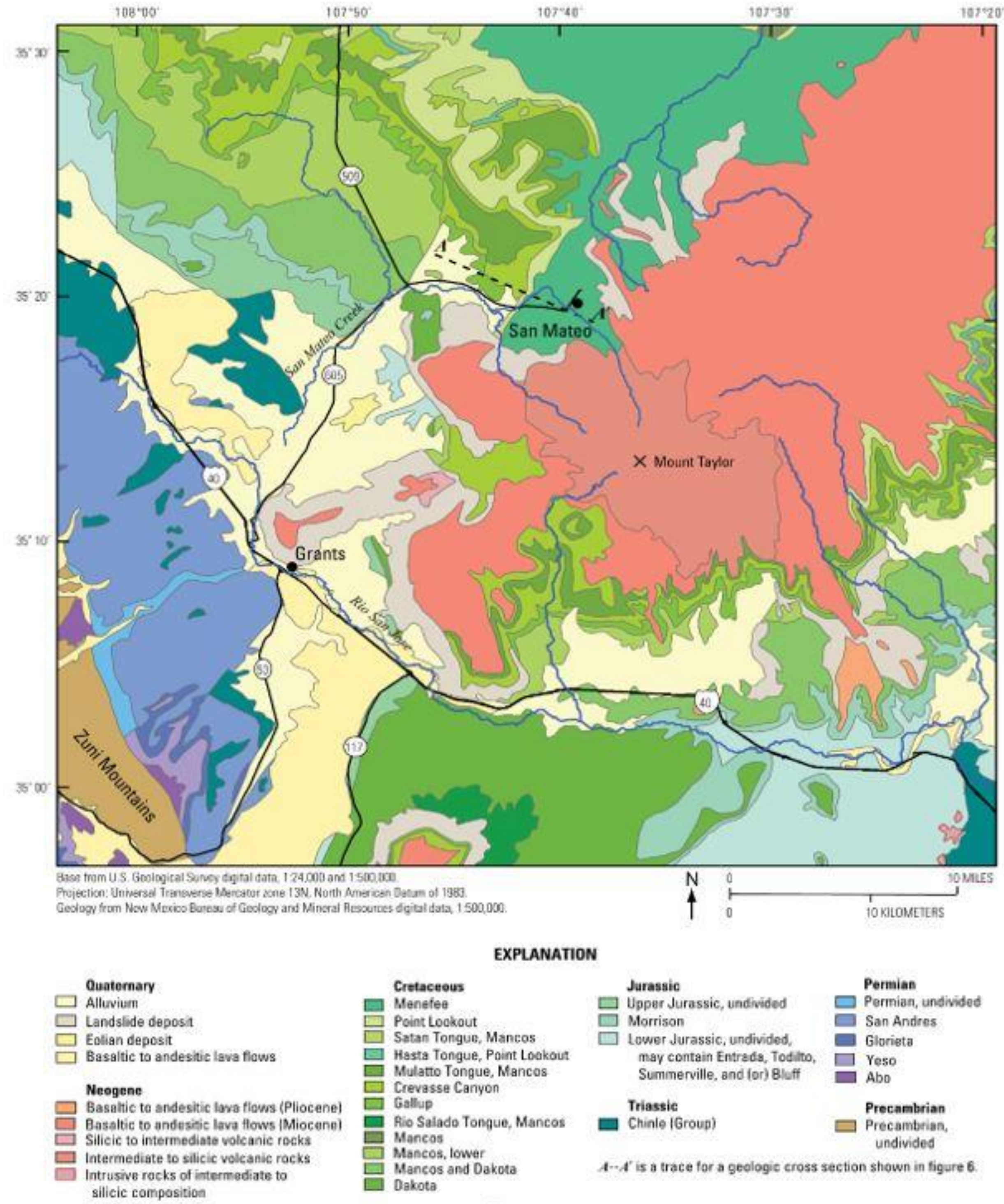


Figure 5. Surface Geology of the San Mateo Creek Basin

Source: Langman et al. 2012

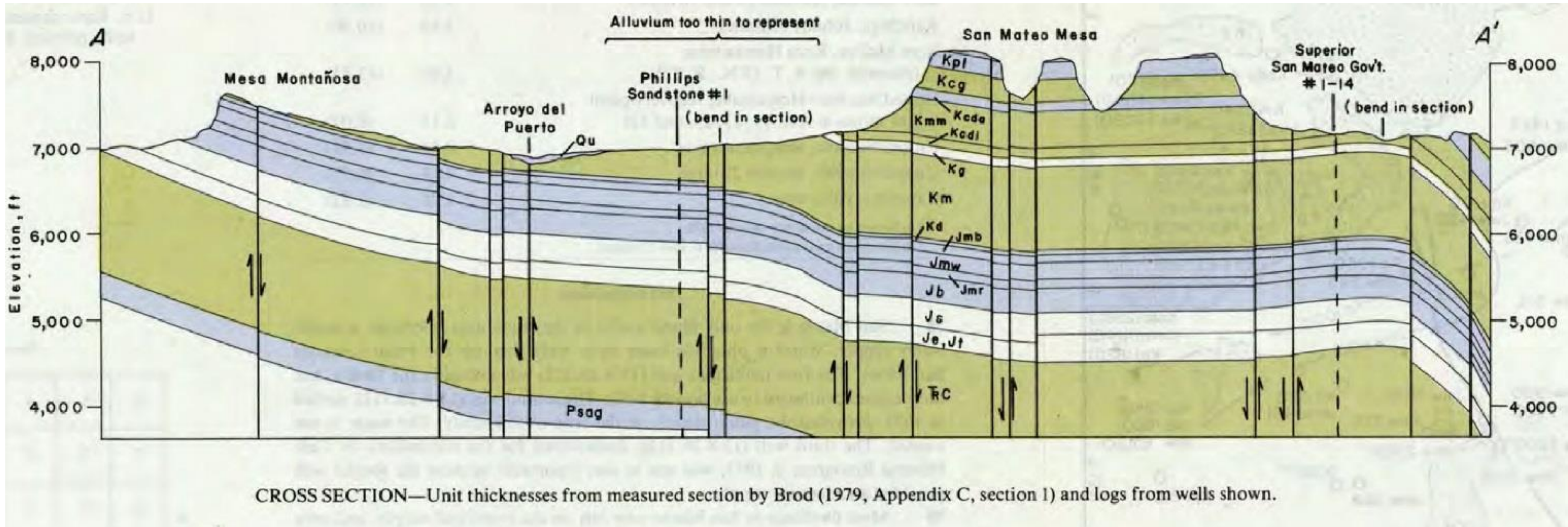


Figure 6. Hydrogeologic Cross Section Through the San Mateo Basin

Source: Brod and Stone 1981

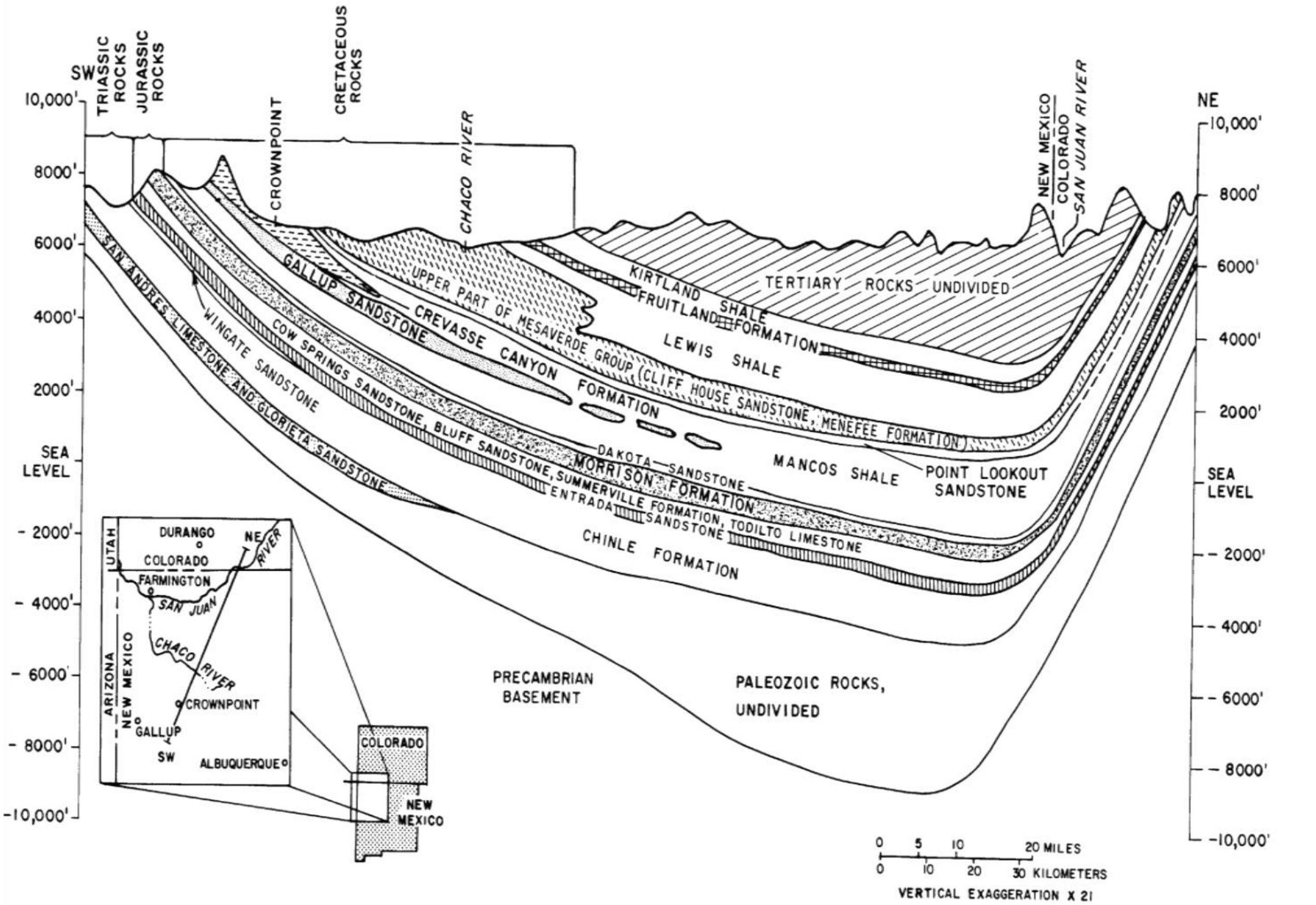


Figure 7. Regional Geologic Cross Section Through the San Juan Basin

Source: Frenzel and Lyford 1982

2.2 Principal Hydrostratigraphic Units and Aquifers

Stone et al. (1983) identified the primary aquifer units in the San Juan Basin, which include groundwater flow originating in the SMC Basin. These include the following (from youngest to oldest):

- Quaternary valley fill deposits (alluvium)
- Menefee Formation
- Point Lookout Sandstone
- Crevasse Canyon Formation
- Gallup Sandstone
- Dakota Sandstone
- Morrison Formation
- Bluff Sandstone
- Entrada Sandstone
- San Andres/Glorieta (SAG) aquifer

These units are shown in Figure 7, which includes other units at the scale of the entire San Juan Basin.

Brod and Stone (1981) present an interpretation of aquifer units focused more specifically on the SMC Basin. They categorize the aquifers as alluvium, the Menefee Formation, Point Lookout Sandstone, Crevasse Canyon Formation, Mancos Shale Sandstone, Dakota Sandstone, Morrison formation, Bluff Sandstone, Todilto Sandstone, Chinle Formation, and SAG aquifer. Most of these units are highlighted in blue in the cross section shown on Figure 6.

Langman et al. (2012) provide a detailed summary of regional aquifer properties along with characteristics of other hydrostratigraphic units, including thicknesses and typical flow directions (Table 1). Unlike previous researchers, Langman et al. (2012) characterize the Menefee, Point Lookout, Crevasse Canyon, Gallup, Mancos, and Dakota units as “discontinuous” aquifers in the SMC Basin, suggesting more localized flow zones with discontinuous flows at a larger scale. The Tertiary volcanic rocks shown on Figure 5 are typically ridge-forming units in the SMC Basin and unlikely to form aquifers (Langman et al. 2012). The Morrison Formation, Entrada Complex, and SAG are considered the major aquifers (Table 1).

Groundwater flow in other geologic units is considered limited and is influenced by localized conditions. Langman et al. (2012) note that both the Mancos Shale and Chinle Formation, while producing some water, typically inhibit vertical (and some horizontal) flow due to the presence of thick sequences of low-permeability shale.

The alluvial, SAG, and permeable horizons in the Chinle are the units present beneath the HMC Mill site and local details are discussed in Section 3.2.

Table 1. Stratigraphic, Lithologic, and Aquifer Characteristics of Geologic Deposits and Formations in the SMC Basin

[ft, feet; %, percent; NA, not available; <, less than]

Deposit/ formation	Geologic age	[1]Deposit/formation description	Surface location in the target area (figs. 4 and 8)	Thickness (ft)	Porosity/ permeability	[1]Direction of flow	Aquifer present
			Quarternary				
Alluvium (Qa)	Quaternary—upper Pleistocene to Holocene	Alluvium eroded from surrounding formations	Valley floor	Highly variable	Possibly large permeability	Variable	Yes
			Neogene				
Flows and volcanoclastics (Tnv and Tpb)	Neogene	Lava, pyroclastic flows, and associated volcanoclastics from the Mount Taylor Volcanic Field	Forms mesa caps on basin highlands	Highly variable	Possible large porosity in vesicular basalts, but low permeability unless fractured	Away from Mount Taylor	Unlikely as an aquifer. Likely runoff or percolation to underlying formations
			Cretaceous				
Menefee (Kmf)	Late Cretaceous	Interbedded mudstones, siltstones, fine- to medium-grained sandstones, mudstones, and thin coals	Northeastern part of basin	[2]Highly variable (eroded), up to 1,000 ft thick	30% sandstone, 65% shale, decent lense permeability	East to northeast	[3]Discontinuous
Point Lookout (Kpl)	Late Cretaceous	Medium to fine-grained, cross-bedded sandstone	Exposed along northern rim areas	[4,5]120	Likely porous with sandstone dominance	East to northeast	[3]Discontinuous
Crevasse Canyon (Kcc)	Late Cretaceous	Interbedded siltstone, sandstone, and coal with thin conglomerates	Exposed along rim	[5]800	Highly variable	East to northeast	[3]Discontinuous
Mulatto Tongue of Mancos (Kmm)	Late Cretaceous	Thin-bedded, tabular to ripple-laminated sandstone (well to moderately sorted and very fine grained) and black mudstone	Exposed along rim	[5]305	Larger porosity than main body of Mancos shale	East to northeast	[3]Discontinuous
Gallup (Kg)	Late Cretaceous	Cross-bedded, moderately-sorted, very fine- to fine-grained sandstone	Exposed along rim	[5]73–85	Likely porous with sandstone dominance	East to northeast	[3]Discontinuous
Mancos (Km)	Middle Cretaceous	Mudstone and silty mudstone with finely laminated to cross-bedded thin sandstone layers (well sorted and fine grained)	Exposed along base of mesas on northern basin boundary	[5]125–710	Small permeability given dominance of shale layers	East to northeast	[3]Possibly discontinuous
Dakota (Kd)	Middle Cretaceous	[5]Sandstones derived from marine shorefaces, intertongues with Mancos	Exposed along base of mesa on the southwest basin boundary	[5]50–60	Likely porous with sandstone dominance	East to northeast	[3]Possibly discontinuous
			Jurassic				
Morrison (Jm)	Upper Jurassic	Mudstone and sandstone	Minor exposure on La Jara Mesa	[2,5]700	Highly variable	East to northeast	Yes

[5]Entrada Complex—Early to Middle Jurassic composed of the Entrada, Todilto, Summerville, and Bluff Formations

Source: Langman et al. 2012

Table 1. Stratigraphic, Lithologic, and Aquifer Characteristics of Geologic Deposits and Formations in the SMC Basin (cont.)

[ft, feet; %, percent; NA, not available; <, less than]

Deposit/ formation	Geologic age	[1]Deposit/formation description	Surface location in the target area (figs. 4 and 8)	Thickness (ft)	Porosity/ permeability	[1]Direction of flow	Aquifer present
Bluff (Jb)	Middle Jurassic	Sandstone	Not exposed in the basin	[2]<5–300	Small permeability for a sandstone[2]	East to northeast	Yes
Summerville (Js)	Middle Jurassic	Thin alternating beds of mudstone, siltstone, and sandstone	Not exposed in the basin	NA	NA	East to northeast	Yes
Todilto (Jt)	Early Jurassic	Limestone	Not exposed in the basin	NA	NA	East to northeast	Yes
Entrada (Je)	Early Jurassic	[2]A three member formation consisting of upper and lower sandstones with a middle siltstone	Not exposed in the basin	NA	NA	East to northeast	Yes
			Triassic				
Chinle Group (TRc)	Triassic	[7]Mudstone and siltstone with clayey/silty sandstone lenses	Not exposed in the basin	[7]1,250	[7]Small	East to northeast	[7]Yes, but limited aquifer because of dominance of shales
			Permian				
San Andres (Psa)	Late Permian	[8]Marine, upper and lower massive fossiliferous limestone separated by a sandstone unit	Not exposed in the basin	[7]225 (San Andres and Glorieta)	Large permeability	[7]East	Yes, major aquifer
Glorieta (Pg)	Middle to late Permian	[8]Massive, well-sorted, well-cemented, fine- to medium-grained sandstone	Not exposed in the basin		NA	[7]East	Yes, major aquifer
Yeso (Py)	Early Permian	[7,9]Sandstone, clayey sandstone, and siltstone mixed with carbonates and evaporites deposited under marine conditions	Not exposed in the basin	[1]1,000	[7]Small permeability	Unknown	[7]Leaky basal unit for the San Andres/ Glorieta aquifer
Abo (Pa)	Early Permian	[7]Fine- to coarse-grained sandstone, siltstone, and mudstone with conglomerates in the lower unit deposited during continental conditions	Not exposed in the basin	[7]1,000	[7]Small permeability	Unknown	[7]Leaky confining unit

[1]Descriptions from McCraw and others (2009) and New Mexico Bureau of Geology and Mineral Resources (2003) unless otherwise noted. The flow-direction indication depends on the study area of the cited references. According to the references, flow directions were mostly northeastward closer to the Zuni Mountains and more eastward closer to the McCarty Syncline under Mount Taylor (fig. 3).

[2]Stone and others, 1983.

[3]Given a review of existing local and regional information, a productive aquifer is unlikely present in these formations within the study area but small amounts of groundwater may be present.

[4]Maximum thickness.

[5]Roca Honda Resources, LLC, 2009a.

[6]Entrada Complex—this term is used solely for this report to describe the early to late Jurassic deposits that have not been well discriminated in the study area. The Entrada is the dominant formation and the presence of the Todilto has been identified by the authors from review of driller's notes. The presence of Bluff and Summerville Formations in this area is debatable and beyond the scope of this report.

[7]Baldwin and Anderholm, 1992.

[8]Gordon, 1961.

[9]Baars, 1962.

Source: Langman et al. 2012

2.3 Groundwater Recharge, Discharge, and Flow Directions

The SMC Basin is primarily a zone of recharge to groundwater, both to shallow and deeper hydrostratigraphic units. Discussion of groundwater recharge, discharge, and flow characteristics for each of the principal aquifers is provided in the following sections.

2.3.1 Quaternary Alluvium

Groundwater flow in near-surface Quaternary deposits (primarily alluvium) is generally similar to topography. Natural recharge to the alluvium is derived from direct precipitation, spring snowmelt, and surface runoff. In general, unconfined groundwater flow follows the courses of Arroyo del Puerto and SMC toward the southwestern portion of the SMC Basin. The full lateral extent of alluvium is typically not saturated, and the occurrence and condition of saturated alluvial material to yield usable quantities of water to a well is discontinuous, highly variable, and transitory (Weston 2016). Brod and Stone (1981) presented water levels from nine locations covering most of the SMC Basin, as shown on Figure 8 (the HMC site is just off the southwest corner of the map). A more extensive regional representation of alluvial groundwater elevations, developed by Baldwin and Anderholm (1992), is shown on Figure 9; the HMC site is about 6 miles (one township) north of Grants on the map. The interpretation shows southwesterly flow in the vicinity of the HMC site with a hydraulic gradient ranging from 10 to 40 feet per mile. It also shows flow southwest out of the SMC Basin and into the alluvium of the Rio San Jose.

Numerous wells have been installed in alluvial materials associated with studies at each of the four mill sites that have been used to characterize recent groundwater flow directions in alluvium in the SMC Basin. Figure 10 shows more recent alluvial groundwater elevation contours in alluvium of Arroyo del Puerto near the Phillips and Rio Algom mills (northwest of the HMC Mill site). Figure 11 presents groundwater elevations in the alluvium near the Bluewater and HMC mills (the large oval HMC tailings pile is visible in the northeast part of the map). In general, flow directions are consistent with regional patterns; local perturbations due to pumping and recharge in the vicinity of the HMC Mill site are discussed in Section 3.3.1

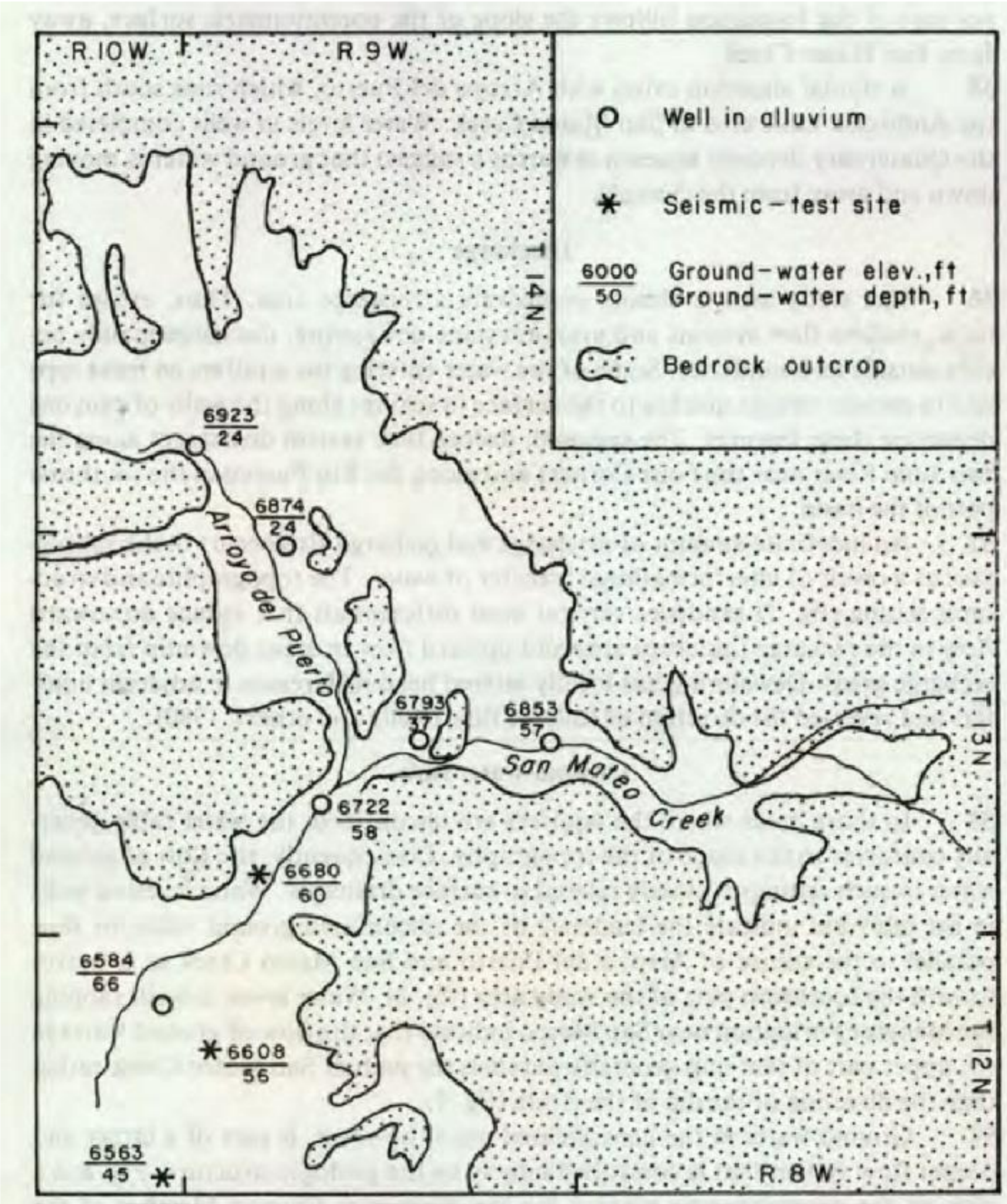


Figure 8. Historical Alluvial Groundwater Elevations and Depths in San Mateo Basin

Source: Brod and Stone 1981

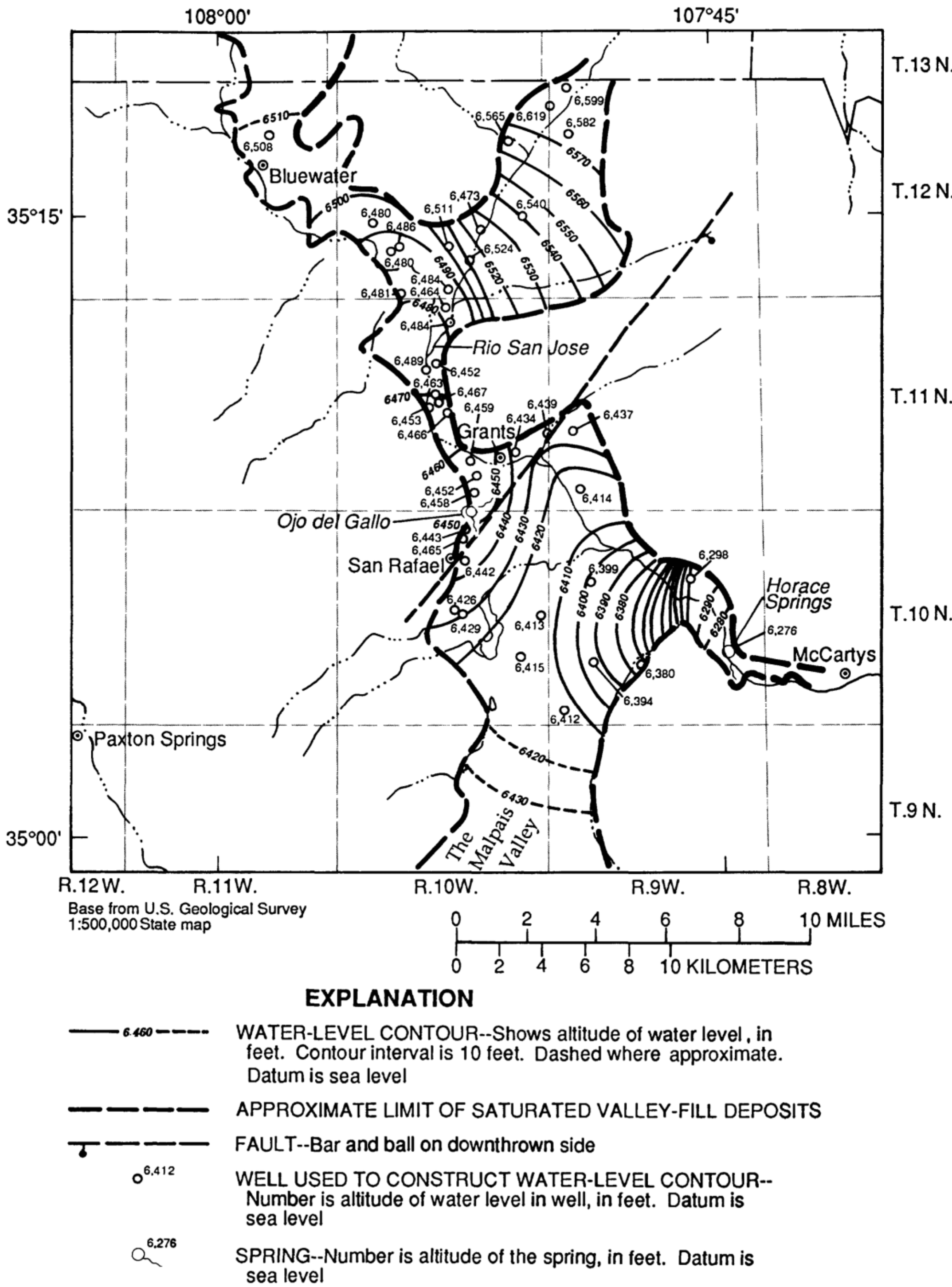


Figure 9. Historical Regional Alluvial Groundwater Levels

Source: Baldwin and Anderholm 1992

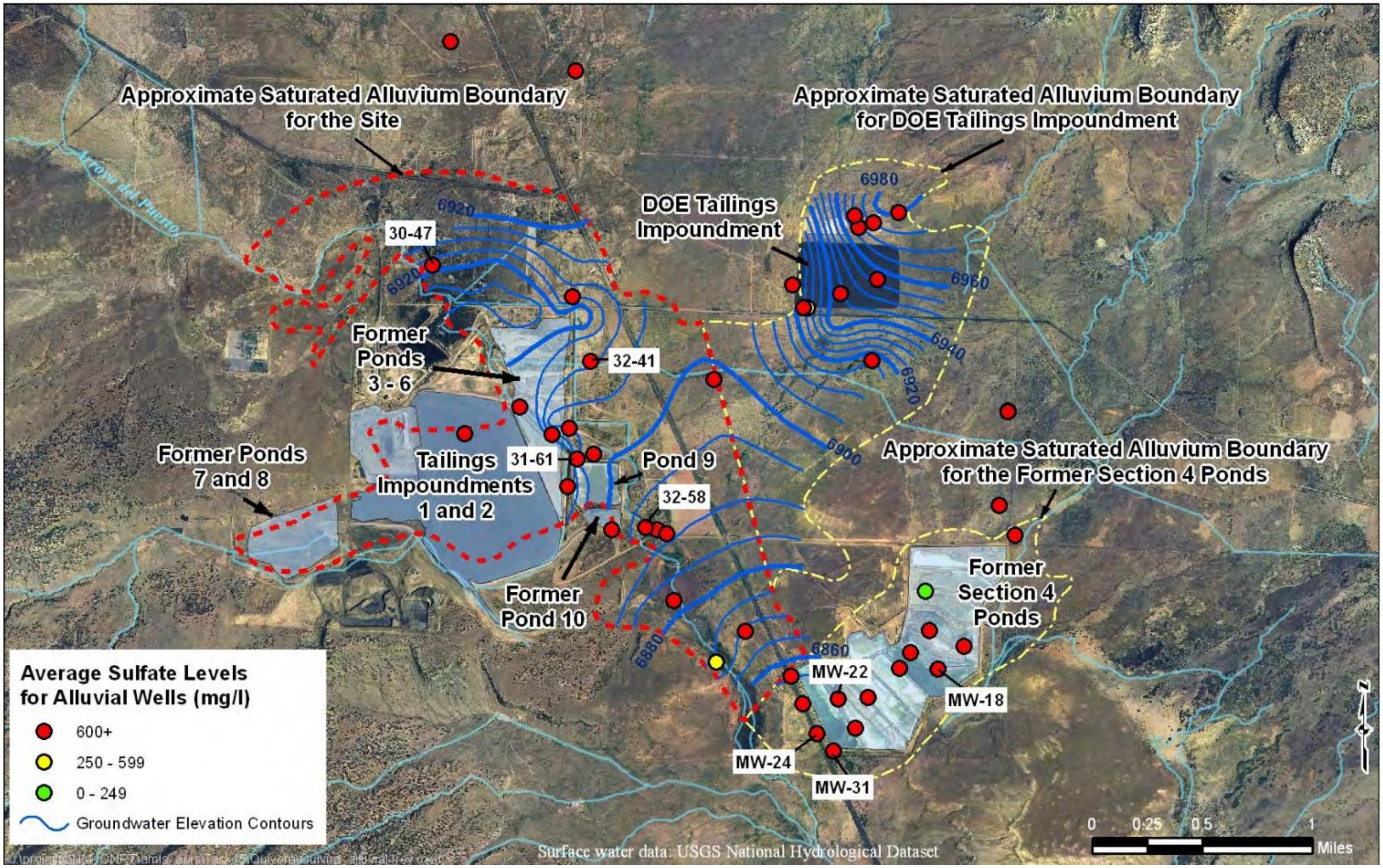


Figure 10. Alluvial Groundwater Elevations Near the Phillips and Rio Algom Mills

Source: NMONRT 2010

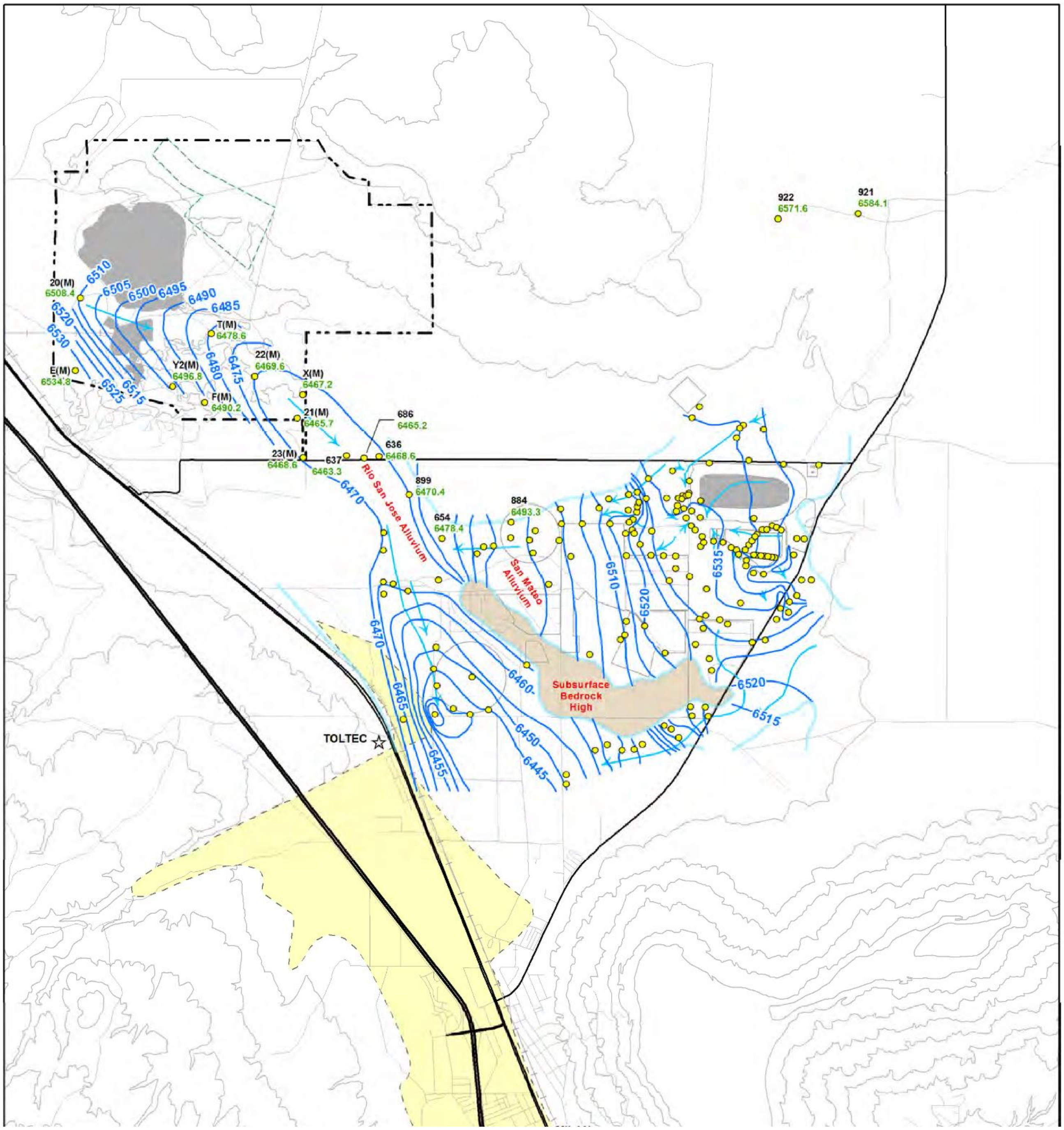


Figure 11. Alluvial Groundwater Elevations in the Vicinity of the Bluewater and HMC Mill Sites

Source: U.S. DOE 2014

2.3.2 Menefee Formation

The Menefee Formation outcrops at the surface in the eastern upper SMC Basin in and near the town of San Mateo (Figure 5). Groundwater in the Menefee is unconfined and receives recharge from direct precipitation, spring snowmelt, and surface runoff. Flow is generally toward the west and discharges into alluvium of SMC. Groundwater also discharges from the Menefee as spring flow into El Rito, San Lucas, and San Mateo creeks. Figure 12 presents a potentiometric surface map for the Menefee Formation in the vicinity of the town of San Mateo developed by Brod and Stone (1981) showing westerly groundwater flow. The Menefee is not present to the south in the lower SMC Basin (Figure 5).

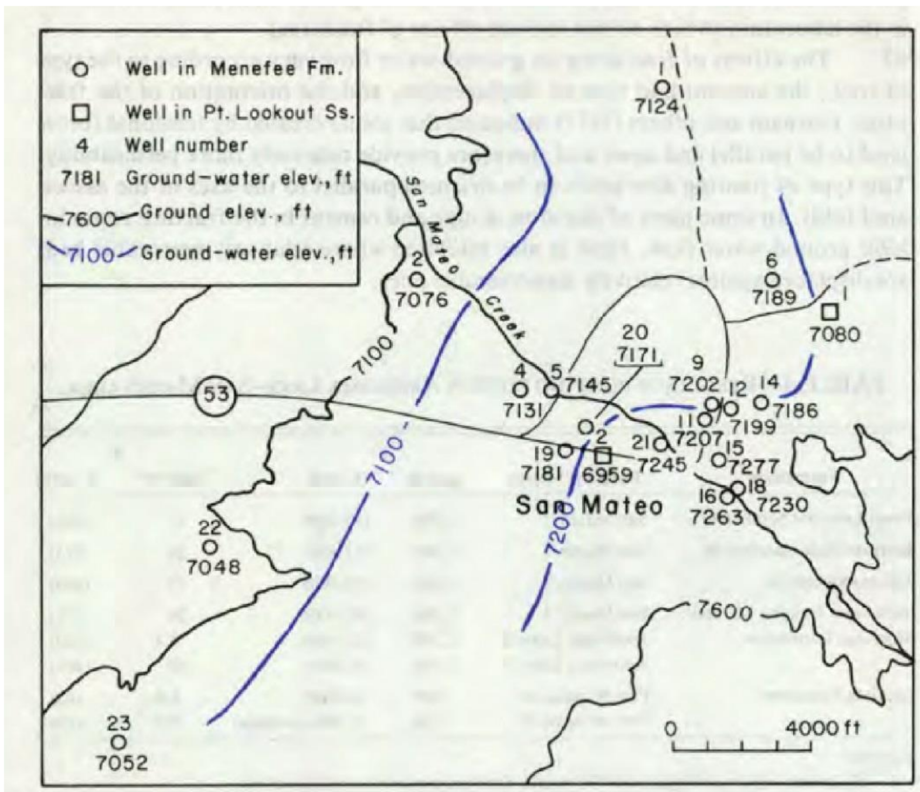


Figure 12. Historical Menefee Groundwater Elevations in the Upper San Mateo Creek Basin

Source: Brod and Stone 1981

2.3.3 Point Lookout Sandstone

Stone et al. (1983) provide a general description of recharge and discharge for regionally extensive Cretaceous and Jurassic aquifers of the San Juan Basin, with recharge occurring primarily in outcrops (and subcrops) on the flanks of the Zuni and Chuska mountains (Figure 13) and Cebolleta Mountains southeast of Grants. Discharge occurs mainly to the San Juan River valley and the Rio Puerco in the southeast part of the San Juan Basin. Frenzel and Lyford (1982) present a generalized map of regional-scale groundwater flow for these aquifers, reproduced here as Figure 13. As shown in the figure, recharge to groundwater in the SMC Basin would be expected to generally flow to the northeast then toward the southeast, ultimately discharging to the Rio Puerco drainage. Variations between aquifers would be expected based on variations in the nature and extent of the Cretaceous and Jurassic units.

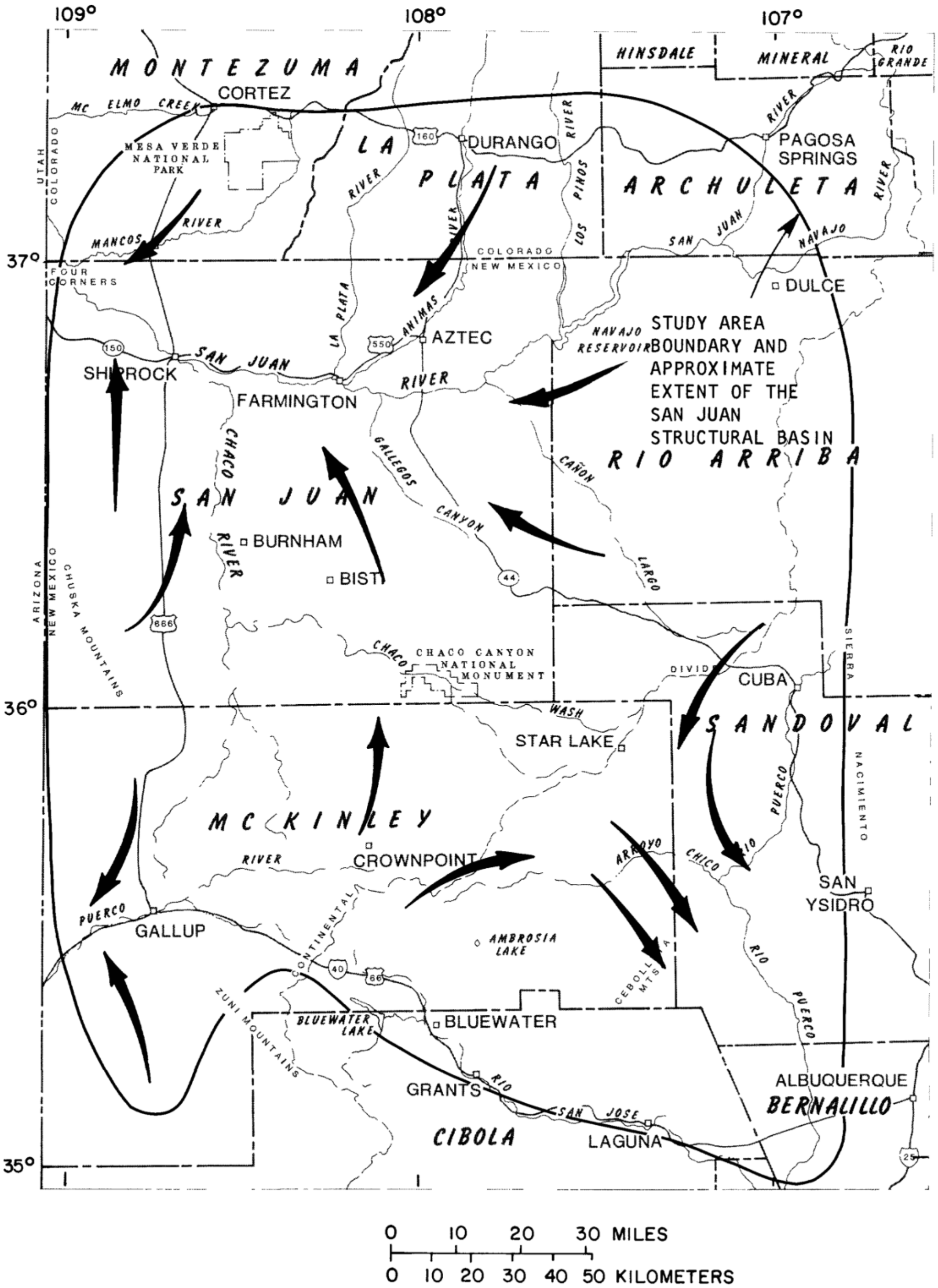


Figure 13. Conceptual Groundwater Flow Directions in Cretaceous and Jurassic Aquifers

Source: Frenzel and Lyford 1982

In the SMC Basin, the Cretaceous Point Lookout Sandstone has extensive outcrops on San Mateo Mesa (northwest of the town of San Mateo, shown on Figure 5) with dips toward the east-northeast. Groundwater recharges the aquifer at the outcrops and the primary regional direction of flow is downdip into the San Juan Basin. Stone et al. (1983) present a regional-scale potentiometric surface map for the Point Lookout Sandstone, shown here in Figure 14. The figure includes an interpretation of outcrop areas receiving recharge, with flow from the SMC Basin primarily northerly.

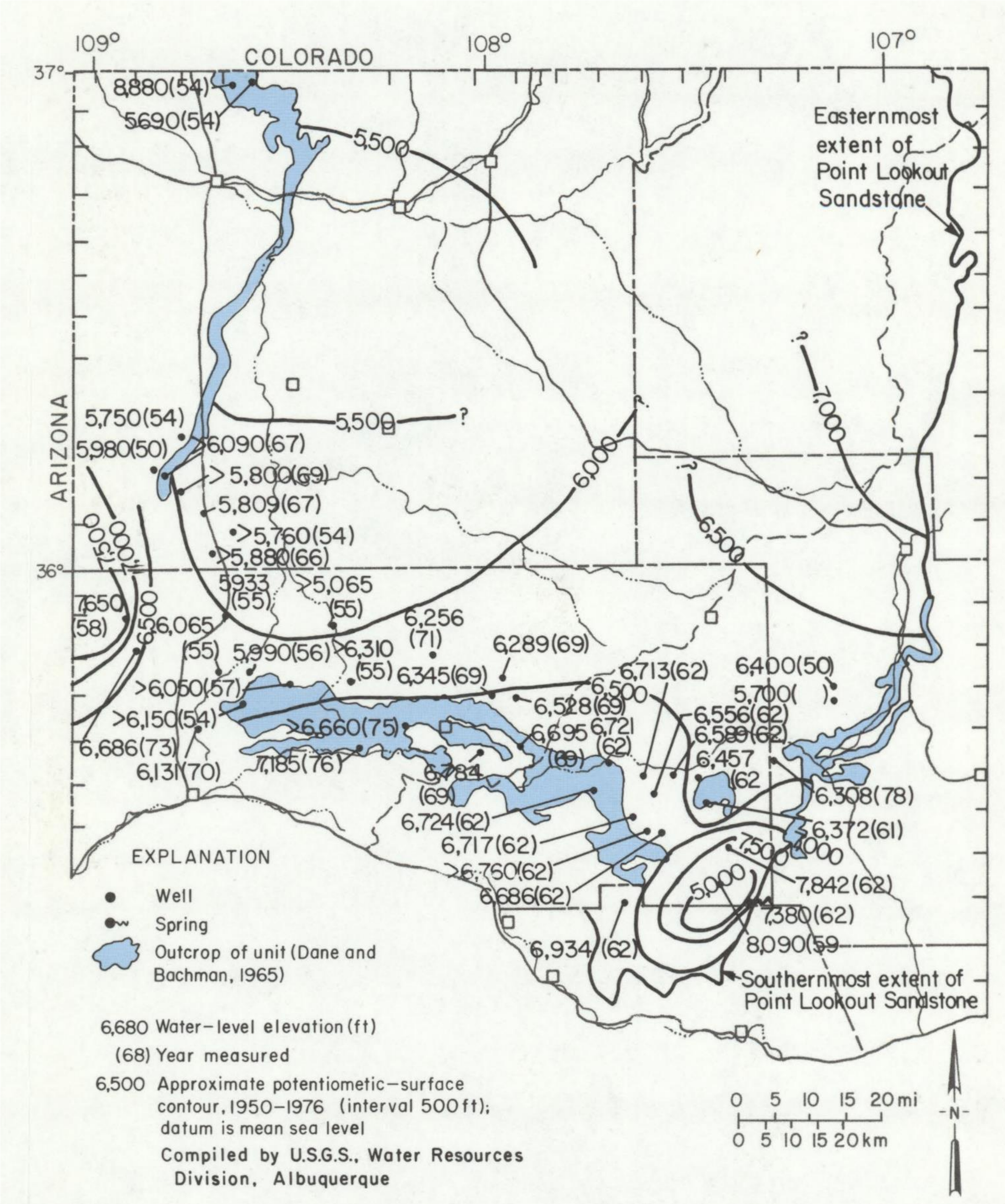


Figure 14. Point Lookout Sandstone Potentiometric Surface Map: San Juan Basin

Source: Stone et al. 1983

2.3.4 Crevasse Canyon Formation

The Crevasse Canyon Formation consists of both sandstone and coal units, with regional groundwater flow occurring primarily in the Dalton Sandstone Member (Stone et al. 1983). Within the SMC Basin, the Formation outcrops on the flanks of San Mateo Mesa, forming uneven slopes (Brod and Stone 1981). The unit dips to the north-northeast. Information on groundwater flow specific to the Crevasse Canyon Formation is not available, but presumably recharge and discharge locations for this unit are similar to the overlying and underlying Point Lookout and Gallup sandstones, with flow directions similar to those shown on Figure 14. Stone et al. (1983) note that many of the wells that produce water from the Crevasse Canyon Formation are also screened across these units.

2.3.5 Gallup Sandstone

Outcrops of the Cretaceous Gallup Sandstone occur in the SMC Basin along the lower flanks of the San Mateo Mesa, dipping north-northeast (Brod and Stone 1981). The Gallup Sandstone underlies the Mulatto Tongue Member of the Mancos Shale in the SMC Basin. A regional-scale potentiometric surface map for the Gallup Sandstone was developed by Stone et al. (1983) as shown on Figure 15. Groundwater flow in this unit is from recharge at outcrops within the SMC Basin toward the north-northwest, ultimately discharging at outcrops occurring at lower elevations near the San Juan River.

Frenzel and Lyford (1982) developed a numerical groundwater flow model simulating flow in the San Juan Basin, focusing on Cretaceous and Jurassic aquifers. The model simulated steady-state flow in the Gallup, Morrison, and Entrada Group aquifers. The Gallup Sandstone was simulated within a model layer that included lower-permeability Mancos Shale in the central portion of the San Juan Basin. Simulated water levels for the Gallup Sandstone are shown on Figure 16. In the SMC Basin, groundwater is simulated as recharge at outcrop areas flowing toward the northeast, ultimately discharging in the Rio Puerco watershed.

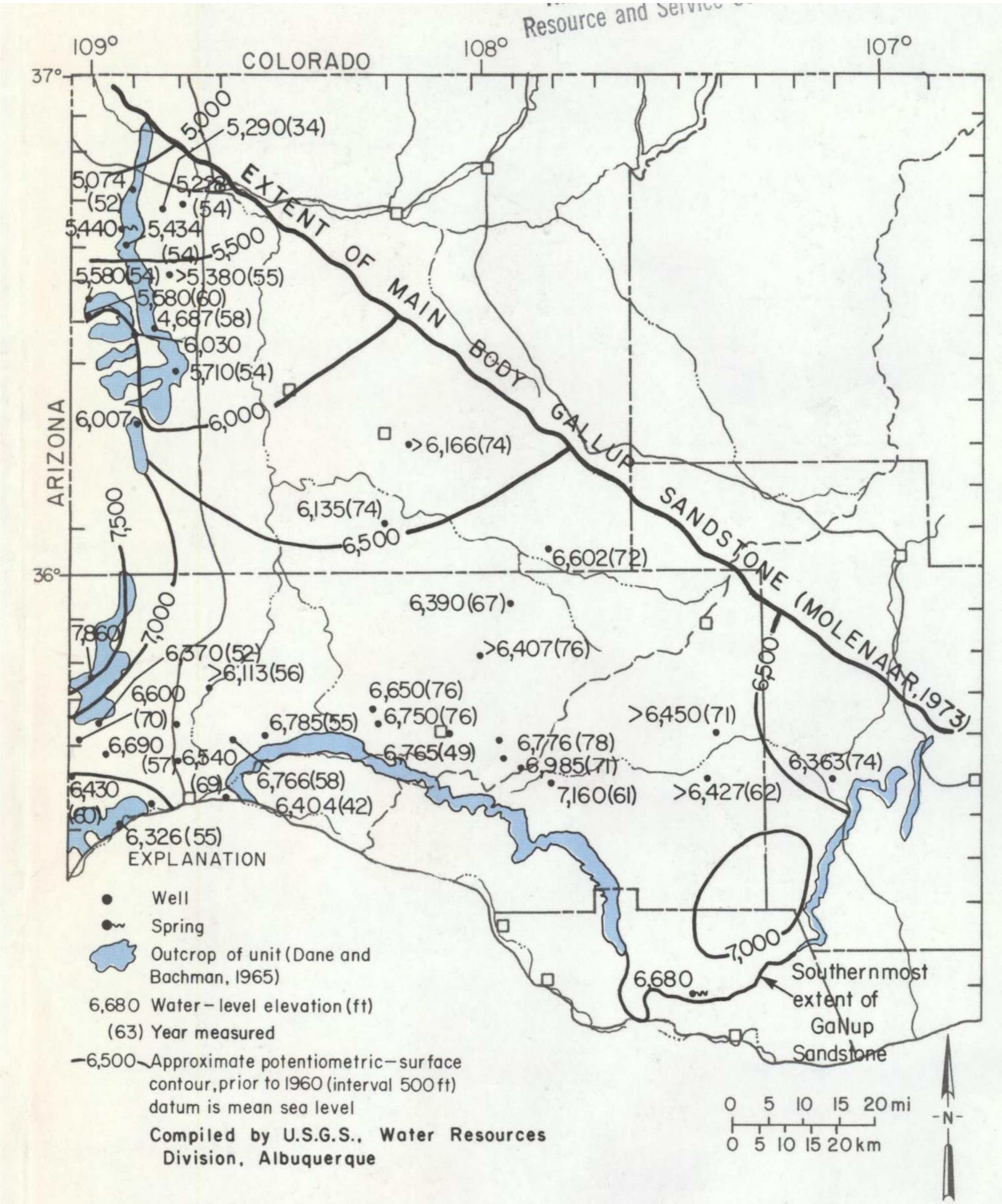


Figure 15. Gallup Sandstone Potentiometric Surface Map: San Juan Basin

Source: Stone et al. 1983

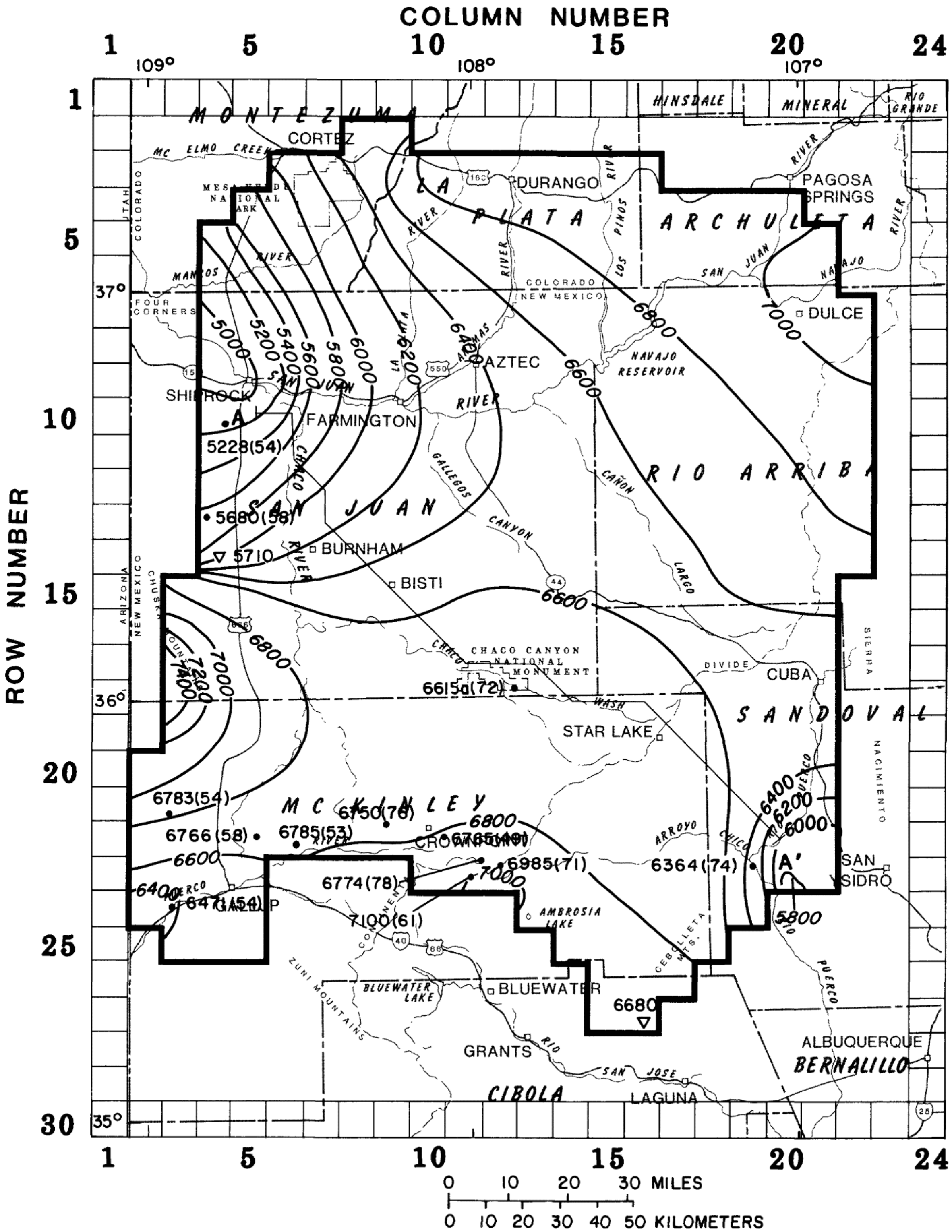


Figure 16. Simulated Potentiometric Surface Map: Gallup Sandstone

Source: Frenzel and Lyford 1982

2.3.6 Dakota Sandstone

The Cretaceous Dakota Sandstone is the lowermost of the Cretaceous units in the southern part of the San Juan Basin. The Dakota Sandstone typically forms a cap on the underlying Morrison Formation, such as the northwest part of the La Jara Mesa, which is located just northeast of Grants and the HMC Mill site (Brod and Stone 1981). Information on groundwater flow specific to the Dakota Sandstone is not available, but presumably recharge and discharge locations for this unit are similar to the underlying Morrison Formation. Stone et al. (1983) note that vertical differences in water levels between the Dakota Sandstone and underlying Westwater Canyon Member of the Morrison persisted in the SMC Basin after mine dewatering lowered heads in the Morrison, which may be interpreted to indicate that mudstones in the upper Morrison Formation (Brushy Basin Member) locally form an aquitard.

2.3.7 Morrison Formation

Outcrops of the Jurassic Morrison Formation in the SMC Basin occur at uneven slopes along the western flanks of Mesa Montanosa (north of the site) and La Jara Mesa, dipping to the north-northeast (Brod and Stone 1981). In the SMC Basin, the Morrison Formation includes the Brushy Basin, Westwater Canyon, and Recapture Member. Regional groundwater flows primarily in the sandstones of the Westwater Canyon Member. The Morrison Formation is the primary host for uranium ore within the SMC Basin, and as such significant mining has occurred in this formation. Mine dewatering has had a significant long-term impact on groundwater flow in this unit, as described in Section 2.5.

Regional-scale groundwater flows from areas of recharge at outcrops along the flanks of the Zuni Mountains toward the north and east. A potentiometric surface map based on 1950s to 1970s data, developed by Stone et al. (1983), is shown as Figure 17, which includes the effect of mine dewatering pumping. Regional groundwater discharge is interpreted to occur at lower-elevation outcrop areas near the San Juan River to the northwest and the Rio Puerco to the southeast. A potentiometric map of a portion the SMC Basin, developed by Brod and Stone (1981), is shown on Figure 18. Pre-mining groundwater is shown flowing from local outcrop areas toward the east-northeast, with a later water-level depression representing the impacts from local mining. Simulated water levels in the Morrison Formation from the model developed by Frenzel and Lyford (1982) are shown on Figure 19 (the HMC site is about 6 miles north of Grants in the southern portion of the map). Groundwater flow is simulated as moving east-southeast from the SMC Basin toward discharge from the model near the Rio Puerco.

The Morrison Formation underlies the Phillips and Rio Algom/Quivira Mills sites in the Ambrosia Lake area (Figures 1 and 2) and groundwater flow in this area has been identified in the Westwater Canyon Member, overlying Dakota Sandstone, and three local sandstone units in the Mancos Shale (designated as the Tres Hermanos A, B, and C, sandstone units). The Tres Hermanos sandstone units subcrop underneath the alluvium of the Arroyo del Puerto, which provides local recharge to these units. In addition, local open wells and shafts may provide a flow pathway from the overlying alluvium downward into the Morrison Formation (NMONRT 2010). Figure 20 shows a cross section in the vicinity of the Phillips and Rio Algom mill sites, which illustrates the local positions of the alluvium, Gallup Sandstone, Mancos Shale, and Morrison units.

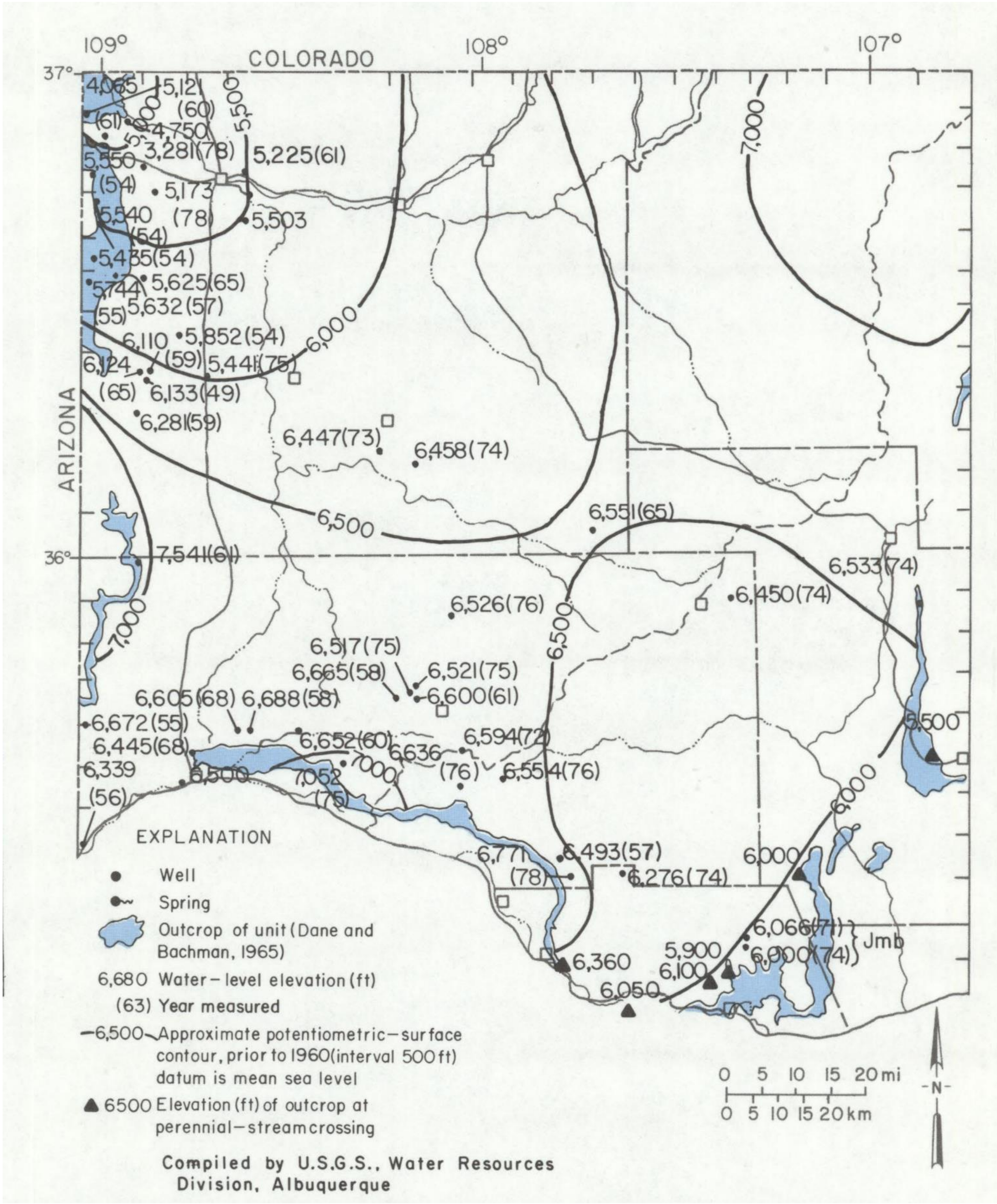


Figure 17. Morrison Formation Potentiometric Surface Map: San Juan Basin

Source: Stone et al. 1983

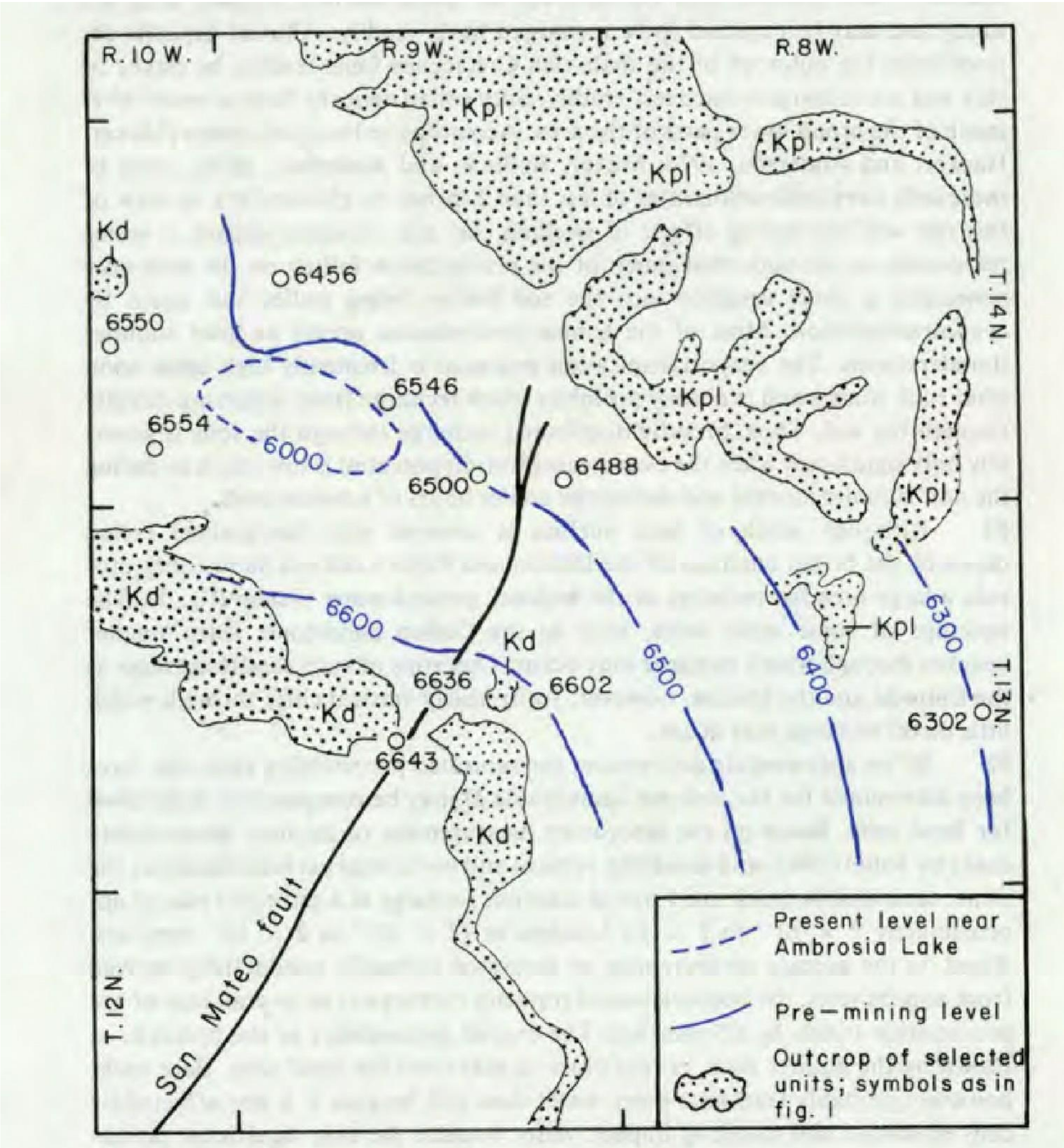


Figure 18. Historical Morrison Groundwater Levels in the San Mateo Creek Basin

Source: Brod and Stone 1981

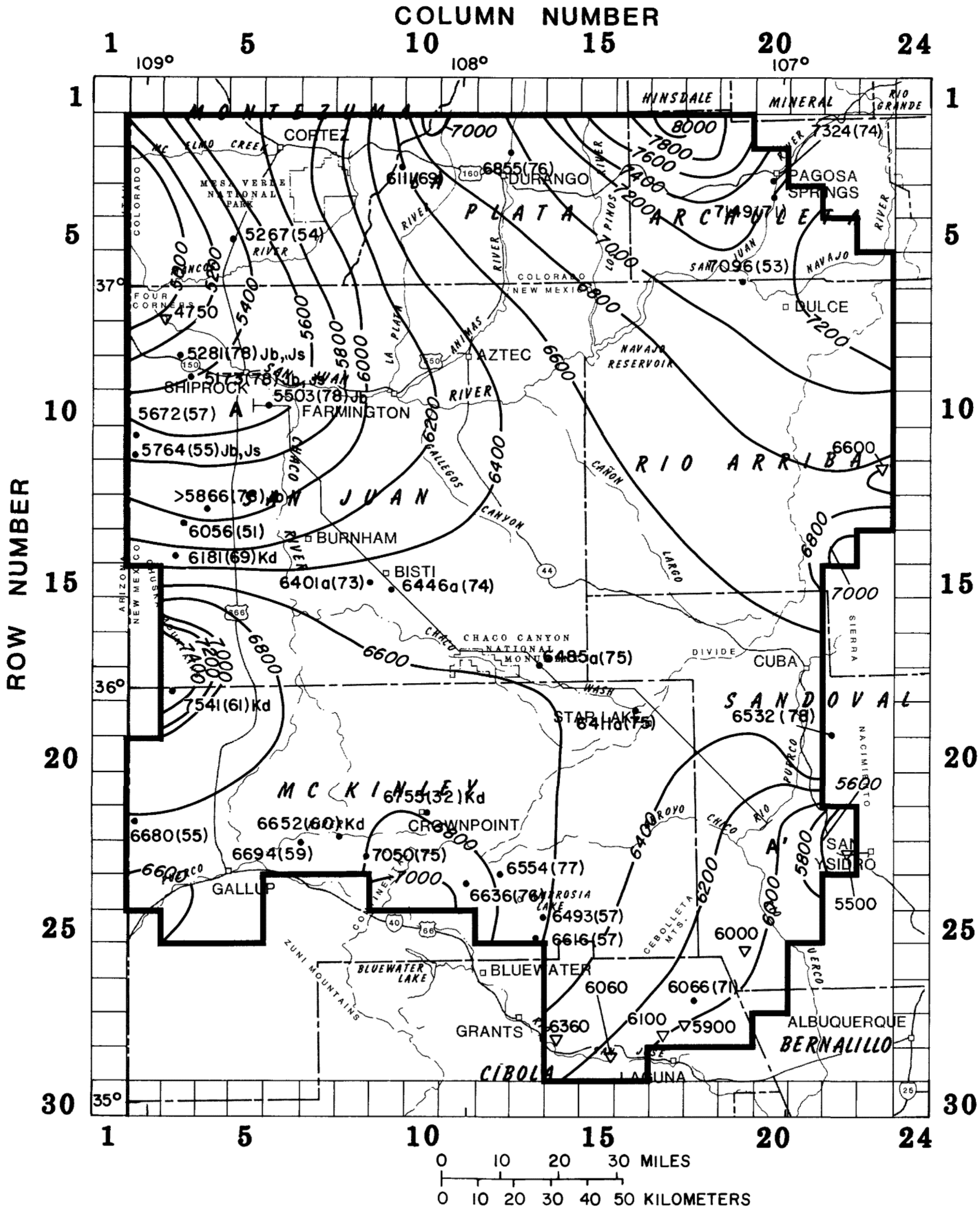


Figure 19. Simulated Potentiometric Surface Map: Morrison Formation

Source: Frenzel and Lyford 1982

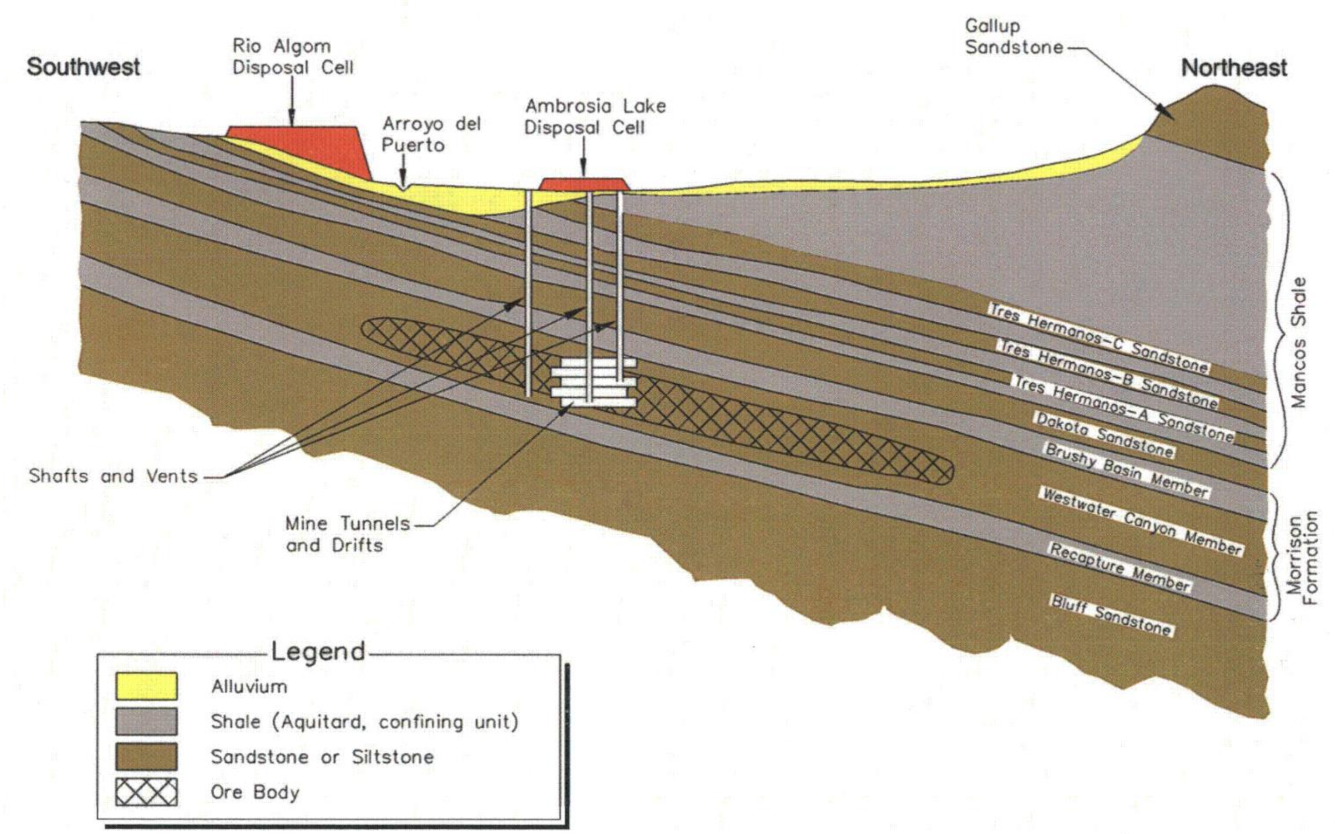


Figure 20. Geologic Cross Section at the Rio Algom Mill Site

Source: U.S DOE 1997

2.3.8 Entrada Complex Sandstones

Langman et al. (2012) identify the Jurassic Entrada Complex (aka San Rafael Group) as being composed of the Bluff, Summerville, Todilto, and Entrada geologic units. Brod and Stone (1981) identify the Bluff and Todilto units as the primary flow units in the SMC Basin, with local outcrops flanking the western side of the Mesa Montanosa and La Jara Mesa. Regional studies such as Langman et al. (2012) identify the Entrada Sandstone as a primary aquifer with flow into the San Juan Basin. Frenzel and Lyford (1982) simulated flow in the Entrada as shown on Figure 21. Flow is simulated in an east-southeast direction from outcrops in the SMC Basin toward discharge in the Rio Puerco watershed.

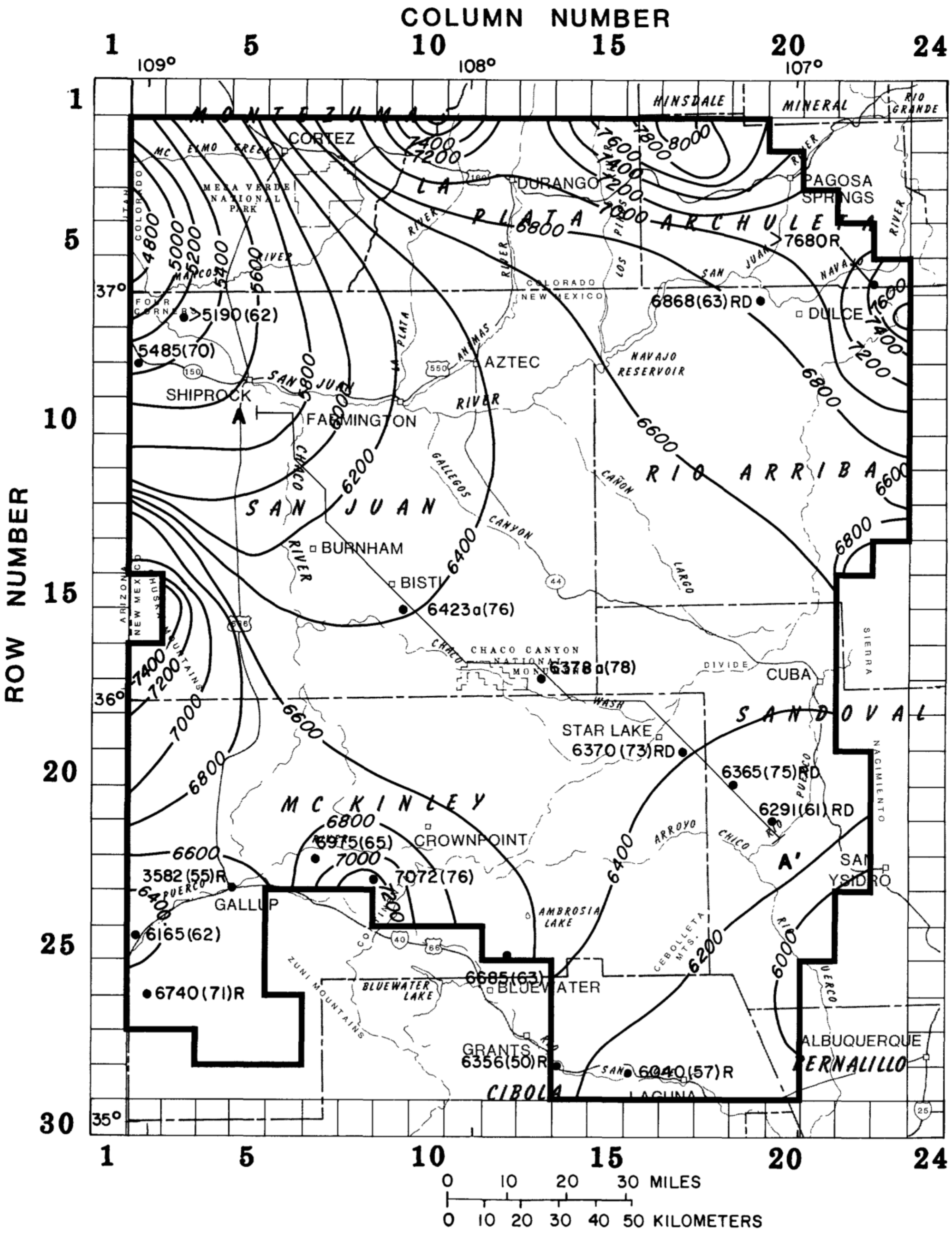


Figure 21. Simulated Potentiometric Surface Map: Entrada Sandstone

Source: Frenzel and Lyford 1982

2.3.9 Chinle Formation

The Triassic Chinle Formation conveys limited amounts of water likely at local scales. Brod and Stone (1981) and Langman et al. (2012) list the Chinle as an aquifer unit, but Langman et al. note that the Chinle generally restricts vertical flow from the overlying Entrada Sandstones to the underlying SAG aquifer. Brod and Stone (1981) note that wells installed in the unit in the SMC Basin produce low flows, generally less than 20 gallons per minute (gpm).

The Chinle Formation outcrops on the flanks of the Zuni Mountains and subcrops underneath alluvium in the southern lower portion of the SMC Basin. The unit thus receives local recharge from vertical flow from the alluvium. Regional information on groundwater flow in the Chinle is not available because it is not a major aquifer, but flow in the Chinle is locally important at the HMC Mill site (HDR 2016) (Section 3.2.2).

2.3.10 San Andres/Glorieta Aquifer

The Permian SAG aquifer forms a primary regional aquifer in the SMC Basin and surrounding area. Groundwater in the SAG aquifer is transmitted in solution channels, cavernous zones, and fractures in the San Andres Limestone, which formed during the period of exposure and erosion related to the unconformity between the San Andres and the overlying Chinle Formation. These features result in very high transmissivities and well yields. The SAG aquifer dips northeast into the San Juan Basin but does not extend into the central part of the basin, as illustrated on Figure 7. The SAG is underlain by the Permian Yeso and Abo formations, which have low permeabilities and form leaky basal confining units for the SAG aquifer (Langman et al. 2012).

Recharge to the SAG aquifer includes outcrops along the Zuni and Lucero uplifts to the south (Figure 5) and south of Grants where the aquifer subcrops beneath the Malpais Valley (Baldwin and Anderholm 1992). Recharge to the SAG aquifer also results from Bluewater Lake and Bluewater Creek (northwest of Grants; Figure 2), and irrigation water return flows in the Grants-Bluewater area. The Bluewater Mill site and tailing pond (Figures 1 and 2) are located above the SAG recharge zone, providing surface flows to the aquifer.

The mechanism of SAG discharge east of the Zuni Uplift is not known. Ojo del Gallo was probably a major discharge point for the SAG aquifer northwest of Grants prior to groundwater resource development (Baldwin and Anderholm 1992). Frenzel (1992) identifies upward flow into valley alluvium and subsequent evapotranspiration and baseflow to surface water as a primary discharge mechanism for the SAG aquifer, as illustrated in Figure 22 (after Frenzel 1992).

Figure 23 presents a regional-scale potentiometric surface map for the SAG aquifer developed by Baldwin and Anderholm (1992). Flow is away from recharge zones near the Zuni Uplift eastward toward the Rio Grande Basin with a hydraulic gradient of approximately 10 feet per mile in the central SMC Basin. Frenzel (1992) developed a detailed numerical model of regional groundwater flow in the SAG aquifer using the United States Geological Survey (USGS) MODFLOW computer code. Simulated groundwater levels in the SAG aquifer representing 1986, shown on Figure 24, are generally eastward in the SMC Basin (north is to the upper right of the map).

The Bluewater Mill site is located above subcrops of the SAG aquifer that receive recharge. Water-level data near the site have been used to assess local-scale flow directions and hydraulic gradients. Figure 25 presents a potentiometric surface map showing flow in the SAG aquifer east-southeast from beneath the Bluewater Mill site toward the HMC Mill site (the large tailings pile is clearly visible in the middle-right portion of the map). These more recent data are consistent with flow directions developed from the earlier studies. Because the SAG aquifer underlies the HMC Mill site, local flow directions are discussed in more detail in Section 3.2.3.

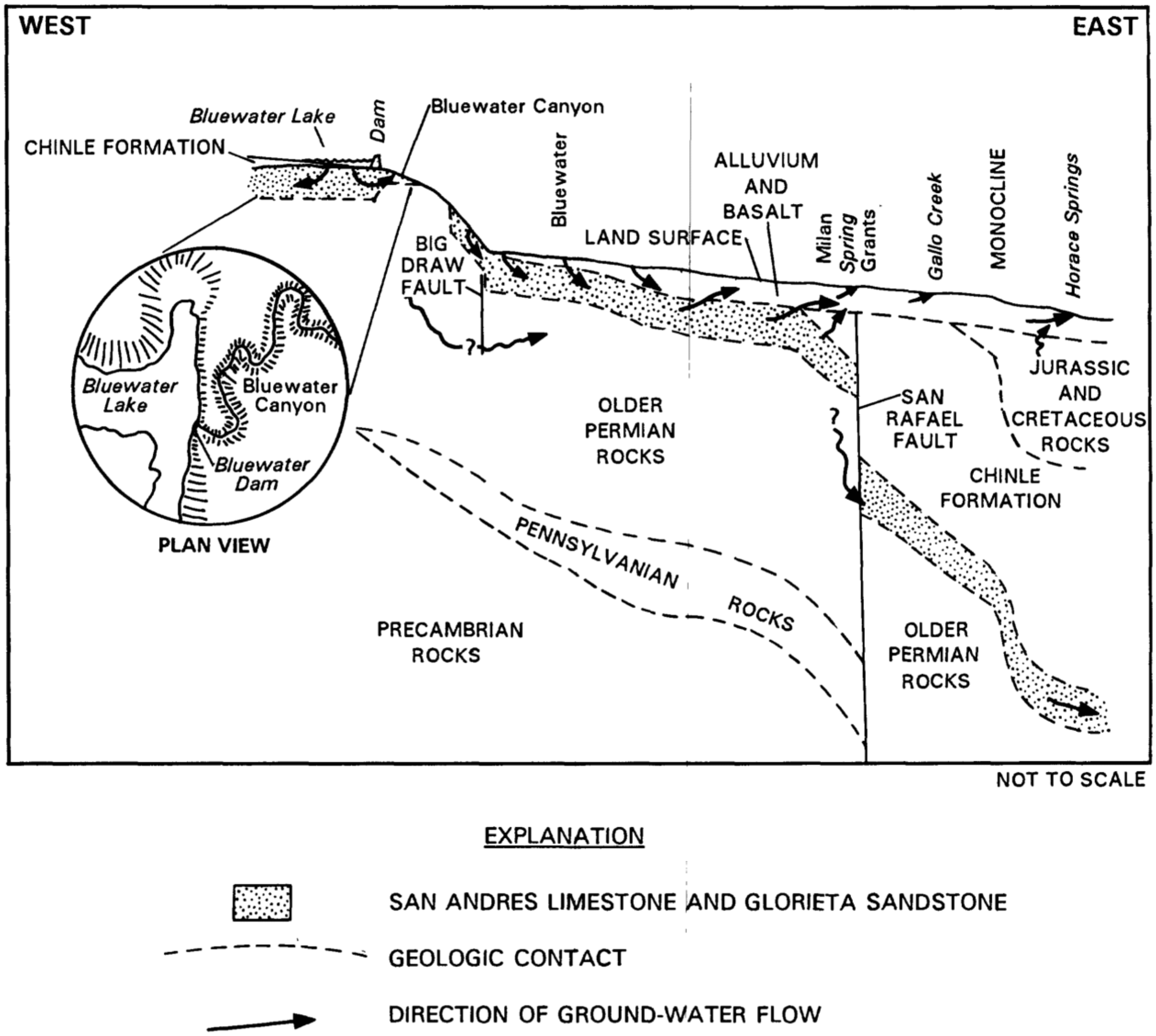


Figure 22. Conceptual Groundwater Flow Paths in SAG Aquifer

Source: Frenzel 1992

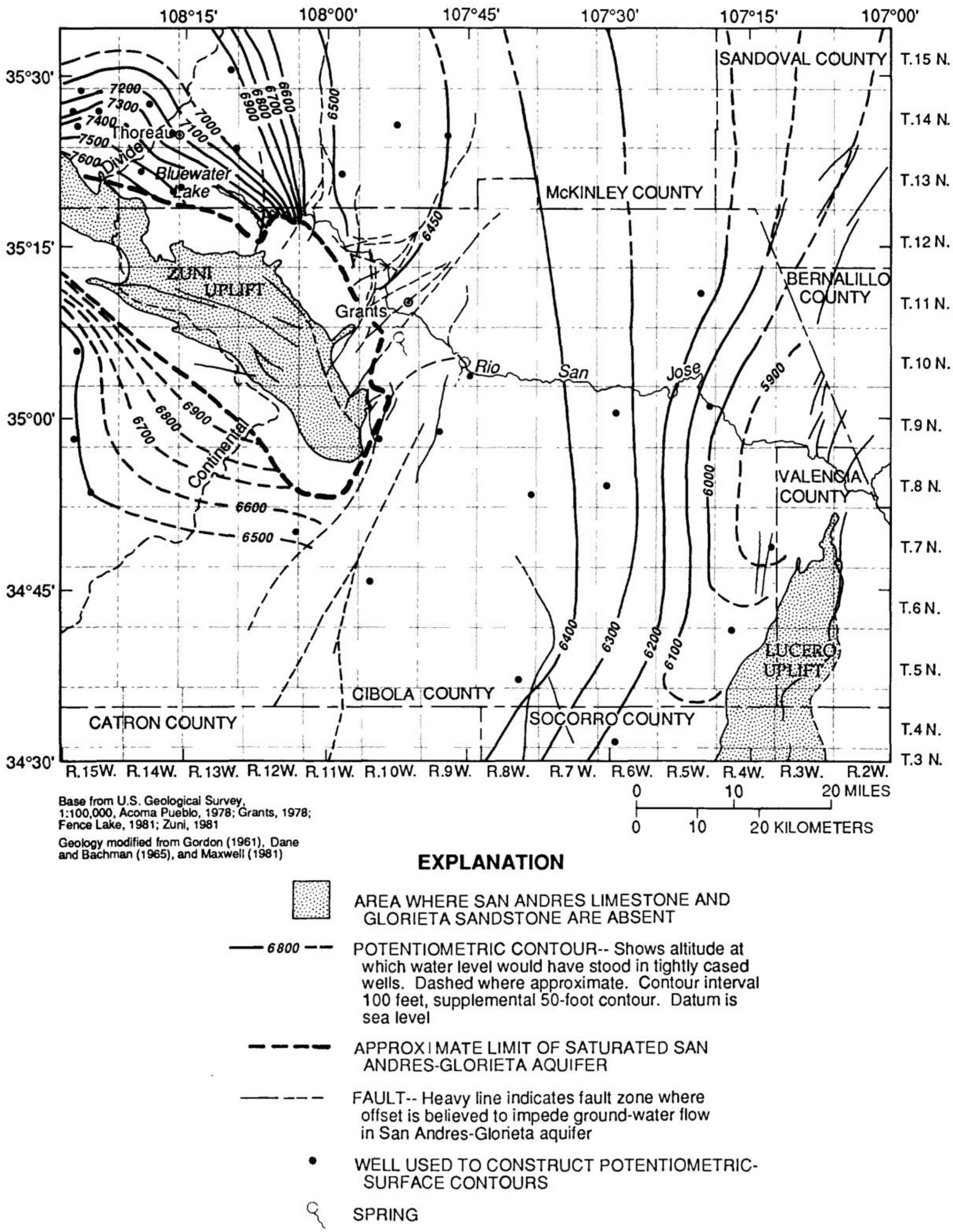
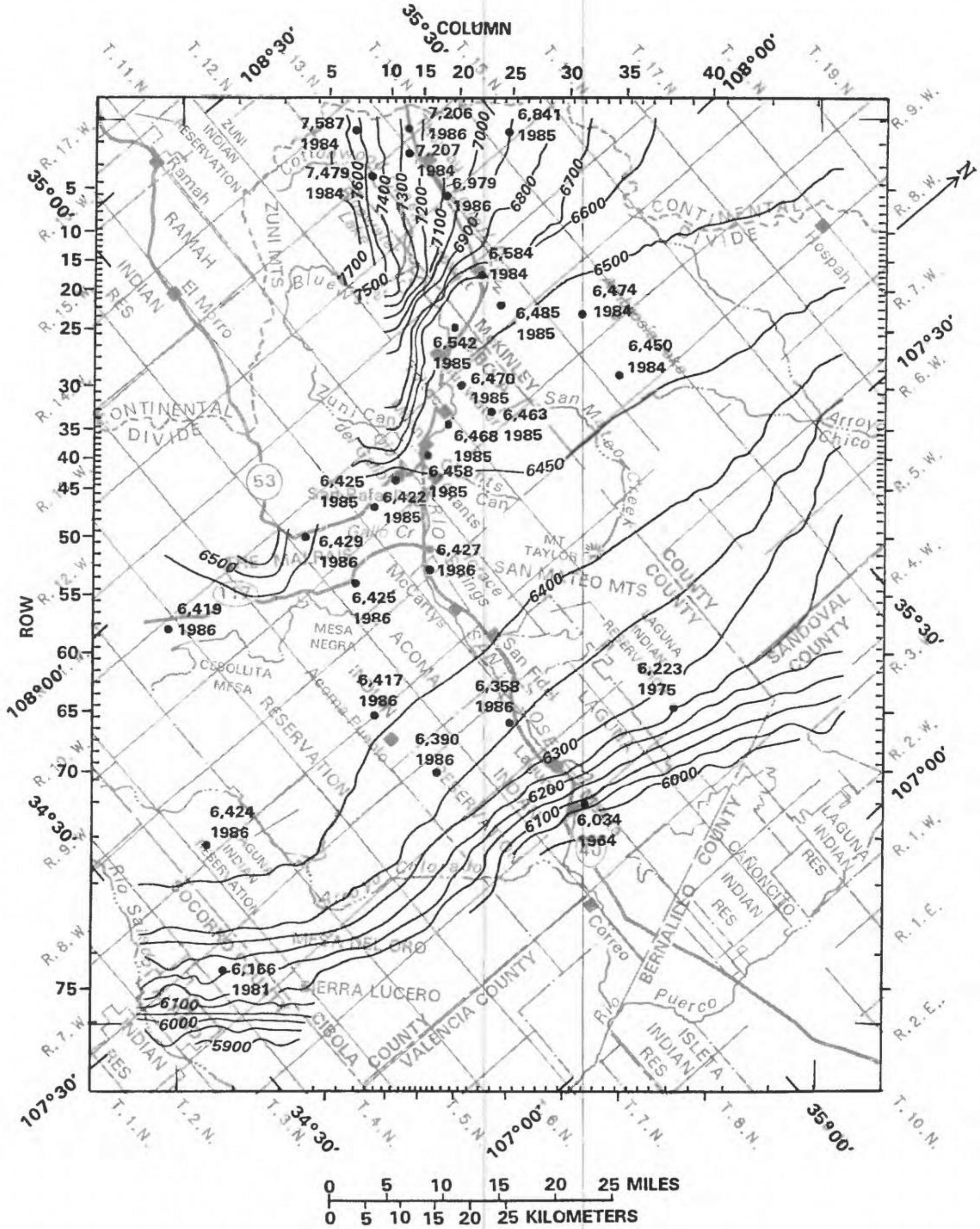


Figure 23. SAG Aquifer Potentiometric Surface

Source: Baldwin and Anderholm 1992



EXPLANATION

5900 — MODEL-DERIVED POTENTIOMETRIC CONTOUR--Shows model-derived altitude of potentiometric surface. Contour interval, in feet, is variable. Datum is sea level

6,166 1981 • WELL--Upper number is measured hydraulic head, in feet above sea level. Lower number is calendar year of measurement

Figure 24. Simulated Potentiometric Surface: SAG Aquifer

Source: Frenzel 1992

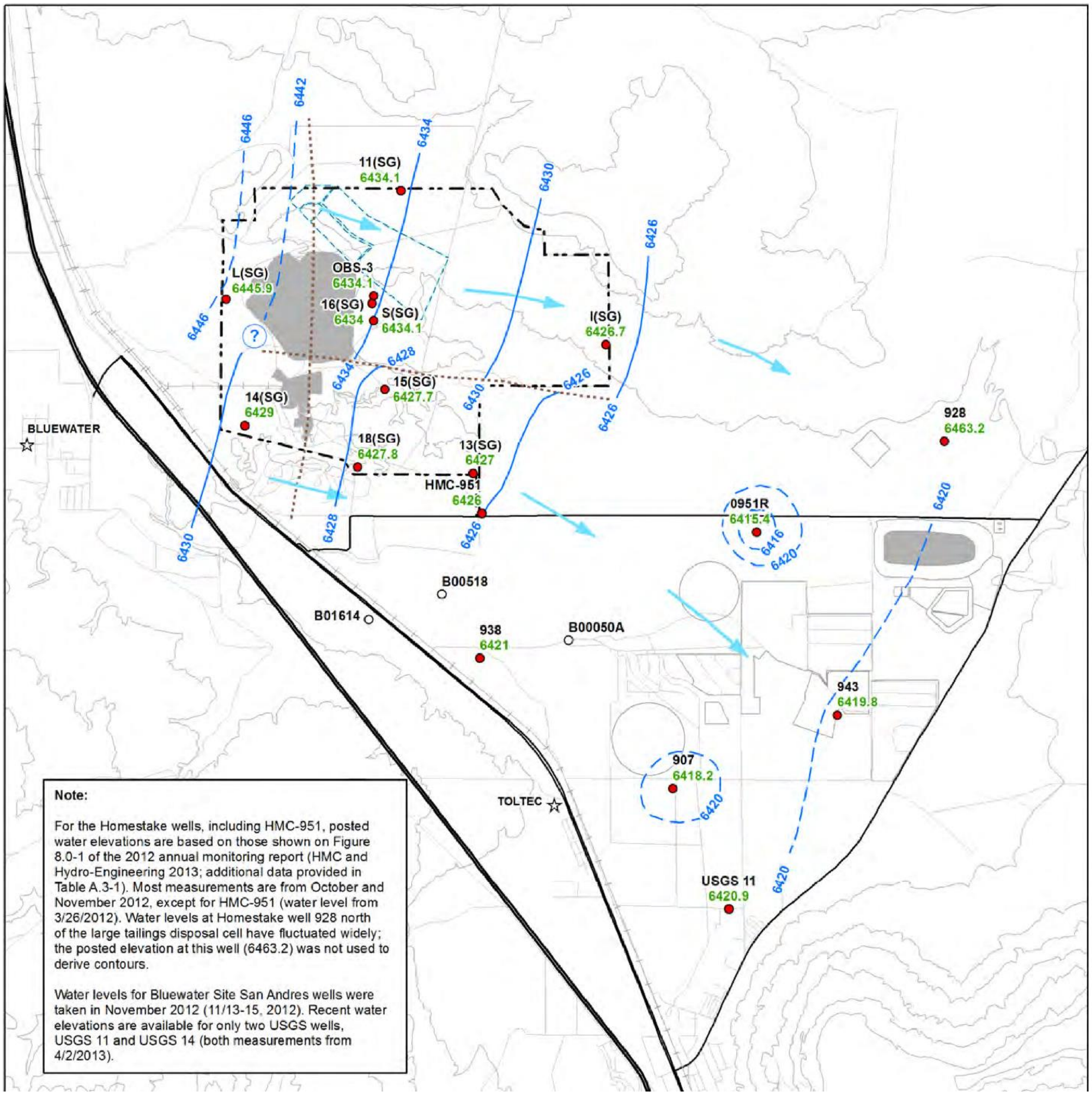


Figure 25. SAG Aquifer Potentiometric Surface Between Bluewater Mill and HMC Mill

Source: U.S. DOE 2014

2.4 Aquifer Physical Properties

Langman et al. (2012) have summarized aquifer thicknesses (Table 1). A summary of median grain sizes, sorting, sand-to-mud ratio, porosity, estimated aquifer transmissivities, and hydraulic conductivities is included in Langman et al. (2012) and is reproduced here (Table 2). In general, the alluvium and SAG aquifers have the highest transmissivities and thus can produce the most water, although alluvial hydraulic conductivities are highly variable. The Chinle Formation's transmissivity and hydraulic conductivities are generally low and highly variable, because it is composed of mudstone mixed with relatively thin sandstones.

Limited data are available on the potential spatial variation in transmissivity in the identified aquifers. Stone et al. (1983) present a generalized map of well-specific capacity and transmissivity in the Morrison Formation for the San Juan Basin, which includes data collected during uranium mining in the SMC Basin. This map is presented in Figure 26. Figure 27 presents a map of transmissivity zones in the SAG aquifer developed by Frenzel (1992) in support of his numerical model of the aquifer (north is to the upper-right corner of the map). The data indicate a high degree of variability.

Data on the storage properties of the aquifers are limited. Stone et al. (1983) cite textbook values for both specific storage and specific yield (1×10^{-6} per foot, 0.1 to 0.3, respectively). Frenzel (1983) extended his original steady-state numerical model to simulate responses to pumping to dewater federal coal leases to the northeast and northwest of the SMC Basin. He assumed a specific storage of 5×10^{-7} per foot for all aquifer units, a specific yield of 0.10 for sandstones, and a specific yield of 0.01 for shale units.

Baldwin and Anderholm (1992) cite estimates of storage coefficients for the SAG aquifer ranging from 5.3×10^{-5} to 0.12 (unitless), noting that the larger estimates are likely representative of specific yields. Frenzel (1992) used a specific yield of 0.12 to represent valley alluvium, and storage coefficients ranging from 4×10^{-4} to 0.15 for San Andres Limestone and Glorieta Sandstone units for numerical modeling.

Table 2. Formation Characteristics Indicative of Horizontal Hydraulic Conductivity Variation among Aquifers in the Area

[S/M, sand to mud ratio; T, transmissivity; ft^2/d, square feet per day; K, hydraulic conductivity; ft/d, feet per day; NA, not available]

Formation	Median grain size	Sorting	S/M ratio	Porosity (percent)	Horizontal T[1] (ft^2/d)	Horizontal K (ft/d)
		Quaternary				
Alluvium (Qa)	NA	NA	NA	NA	NA	[2]2–300
		Neogene				
Flows and volcanoclastics (Tnv and Tpb)	NA	NA	NA	NA	NA	[3]1–1,000+
		Cretaceous				
Menefee (Kmf)	Very fine to fine sand	Poor to moderate	4.6	9	2.7–112	.005–.01
Point Lookout (Kpl)	Fine to medium sand	Moderate to moderately well	19.1	2–9	.4–240	.002–.02
Crevasse Canyon (Kcc), sandstone unit	Fine sand	Poor to well	8.4	4	3–250	NA
Mulatto Tongue (Kmm)	Fine sand	Moderate to very well	5.7	11	NA	NA
Gallup (Kg)	Fine to coarse sand	Moderate	13.7–33.5	4–9	[4]15–390	.1–1.0
Dakota (Kd)	Fine to medium sand	Moderate	6.1–18.2	2–6	[4]44–370	.0004–1.5
		Jurassic				
Morrison (Jm)	Fine sand	Moderate to very well	15.7–101.1	0–10	2–480	[5]0.1
Entrada Complex: Early to Middle Jurassic composed of the Bluff, Summerville, Todilto, and Entrada Formations						
Bluff (Jb)	Medium sand	Poor to well	12	7	3–50	NA
Summerville (Js)	Very fine sand	Moderate to moderately well	6.7–10.8	5–6	8.2	NA
Entrada (Je)	Very fine to fine sand	Extremely poor to very well	1.3–9.8	5–11	.84–400	.5–5
		Triassic				
Chinle Group (TRc)	Mudstone mixed with sandstone and limestone		NA	NA	4.7–100	[6]10^{-8}–10^{-1}
		Permian				
San Andres and Glorieta (Psa and Pg)	Micritic limestone and fine to medium sand		NA	NA	[7]10–450,000	[3]40–60

[1]Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness (Heath, 1983).

[2]Frenzel, 1992; Risser and Lyford, 1983.

[3]Dames and Moore, written commun., 1986.

[4]Possible overlap of test interval between the Gallup and Dakota Formations.

[5]Roca Honda Resources, LLC, 2009b.

[6]Wolff, 1981.

[7]Brod and Stone, 1981; Brod and Stone, 1983; Frenzel, 1992.

Source: Langman et al. 2012; derived

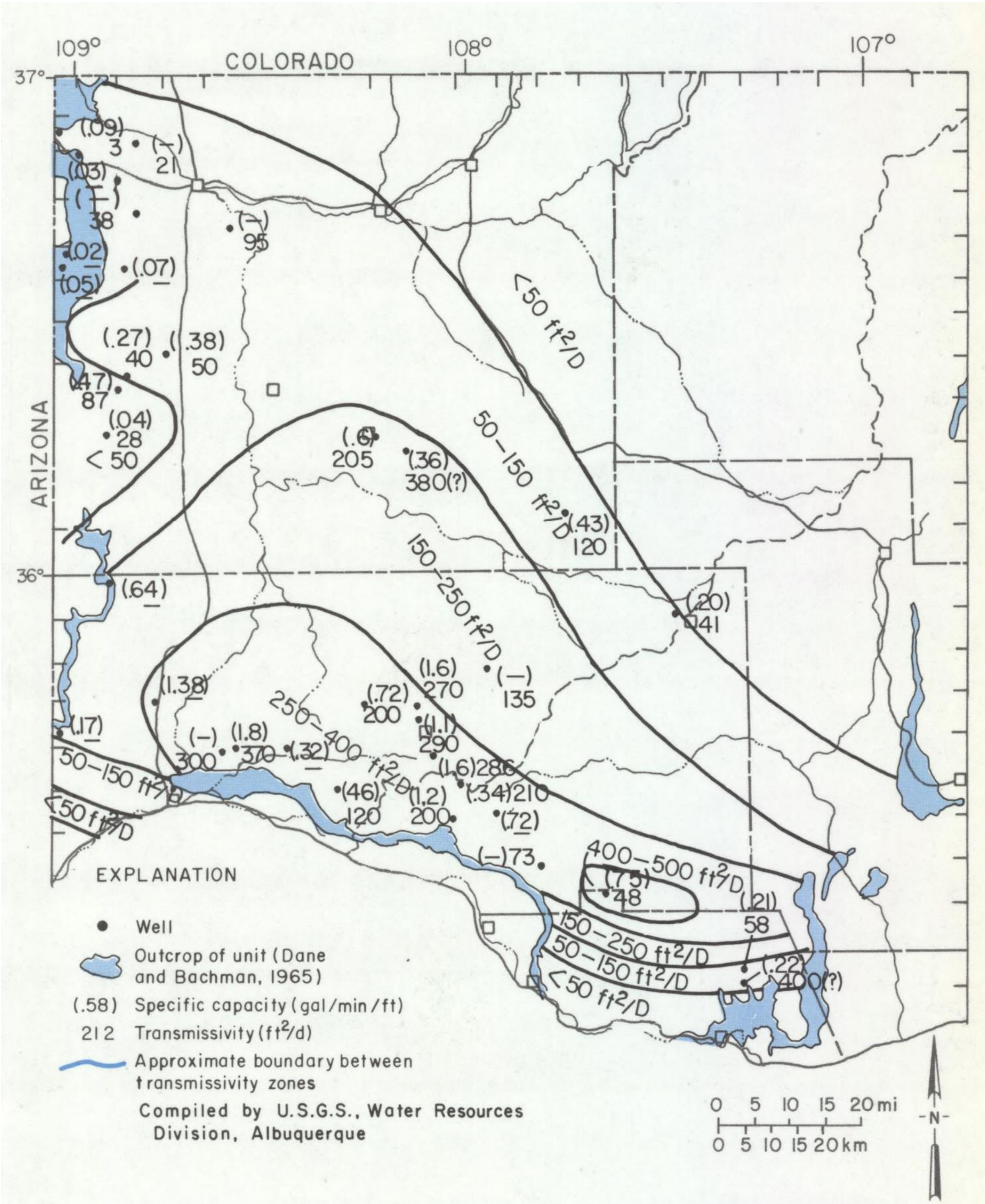


Figure 26. Spatial Variation in Transmissivity: Morrison Formation

Source: Stone et al. 1983

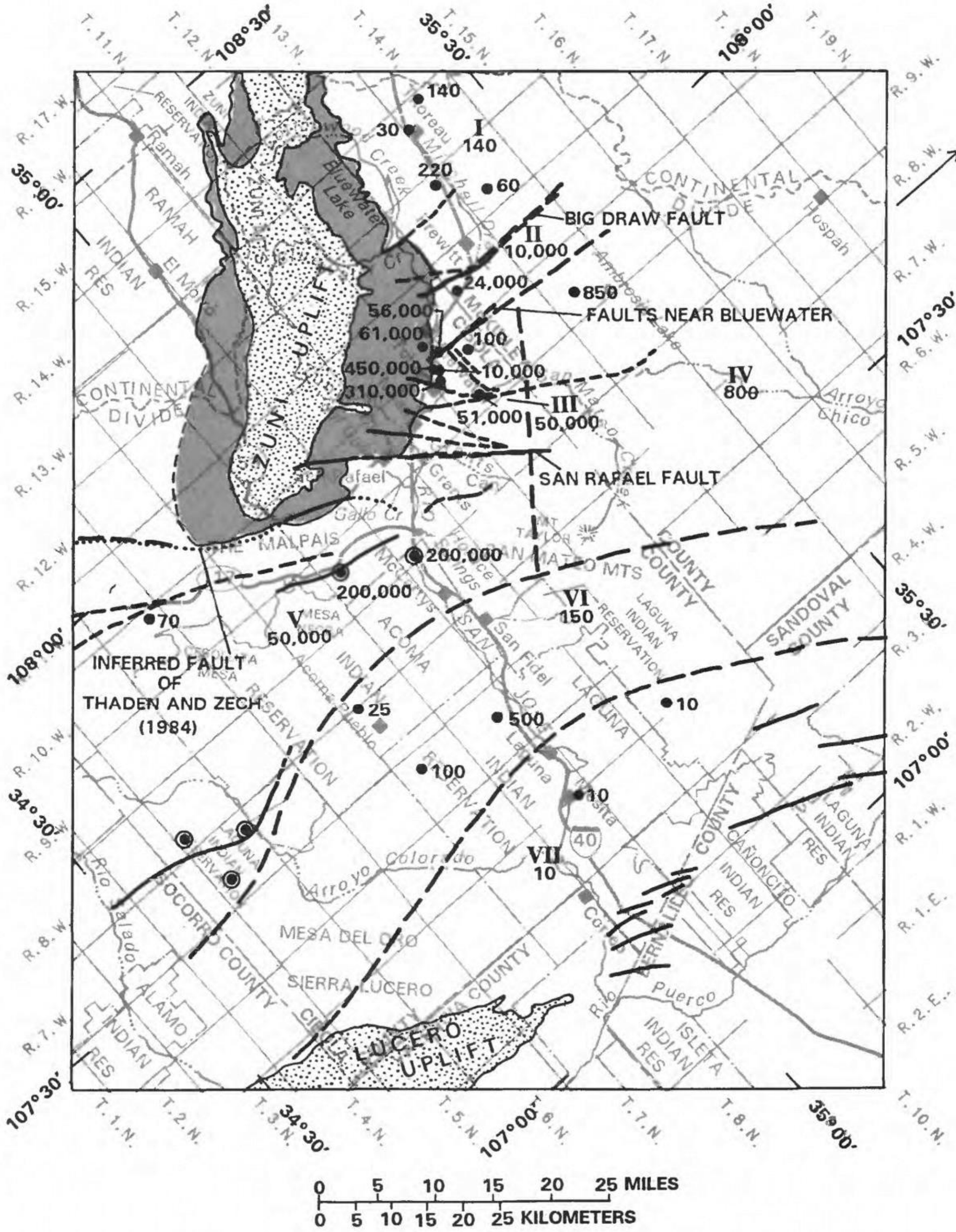


Figure 27. Spatial Variation in Transmissivity: SAG Aquifer

Source: Frenzel 1992

2.5 Effects of Groundwater Extraction on Regional Flow Conditions

Pumping of groundwater over time has had a significant effect on groundwater levels in the primary aquifers in and near the SMC Basin. The following summarizes available information related to pumping in the following three main aquifers in the SMC Basin:

- Alluvium
- Morrison Formation
- SAG aquifer

The effects of local pumping within the alluvium and Chinle Formations at the HMC Mill site related to remediation are discussed in Section 3.3.

2.5.1 Alluvium

Pumping from the alluvium occurs for domestic, stock, irrigation, and industrial purposes. Brod and Stone (1981) noted 25 wells installed in the alluvium in the Ambrosia Lake-San Mateo area at that time. Significant pumping and injection occur in the alluvium associated with remediation at the HMC Mill site, which have generally increased saturated thicknesses in the alluvium near the site.

Historical mine dewatering pumping, discussed in the next section, has had a significant long-term effect on groundwater flows in the alluvium in the SMC Basin. Mining of uranium occurred primarily in the Ambrosia Lake area of the SMC Basin. Groundwater extracted from mine dewatering was either used in the mine process or discharged to local drainages or the ground surface (NMONRT 2010). Much of this discharge flowed to the Arroyo del Puerto and recharged local alluvium. Alluvium in this area was likely unsaturated prior to mining (U.S. DOE 1996; Maxim 2000; Weston 2016). As such, most of the groundwater in alluvial sediments in the Arroyo del Puerto currently is a result of past mining activities, and is not naturally occurring. Recharge of mine discharge over an approximately 25-year period has resulted in increased flow downgradient in the Arroyo del Puerto and ultimately SMC.

Figure 28 presents a hydrograph showing long-term water levels measured in alluvial Well R, located approximately 1 mile upgradient (north) of the HMC Mill site. Water levels show a continuous increasing trend in water levels, from an elevation of approximately 6,548 feet above mean sea level (ft amsl) in early 1976 to 6,564 ft amsl in late 2016. The slow, multi-decadal rise in alluvial groundwater levels (approximately 2.7 feet per year) is interpreted as the result of slow groundwater movement downgradient of historical mine and remediation discharges to the alluvium of SMC.

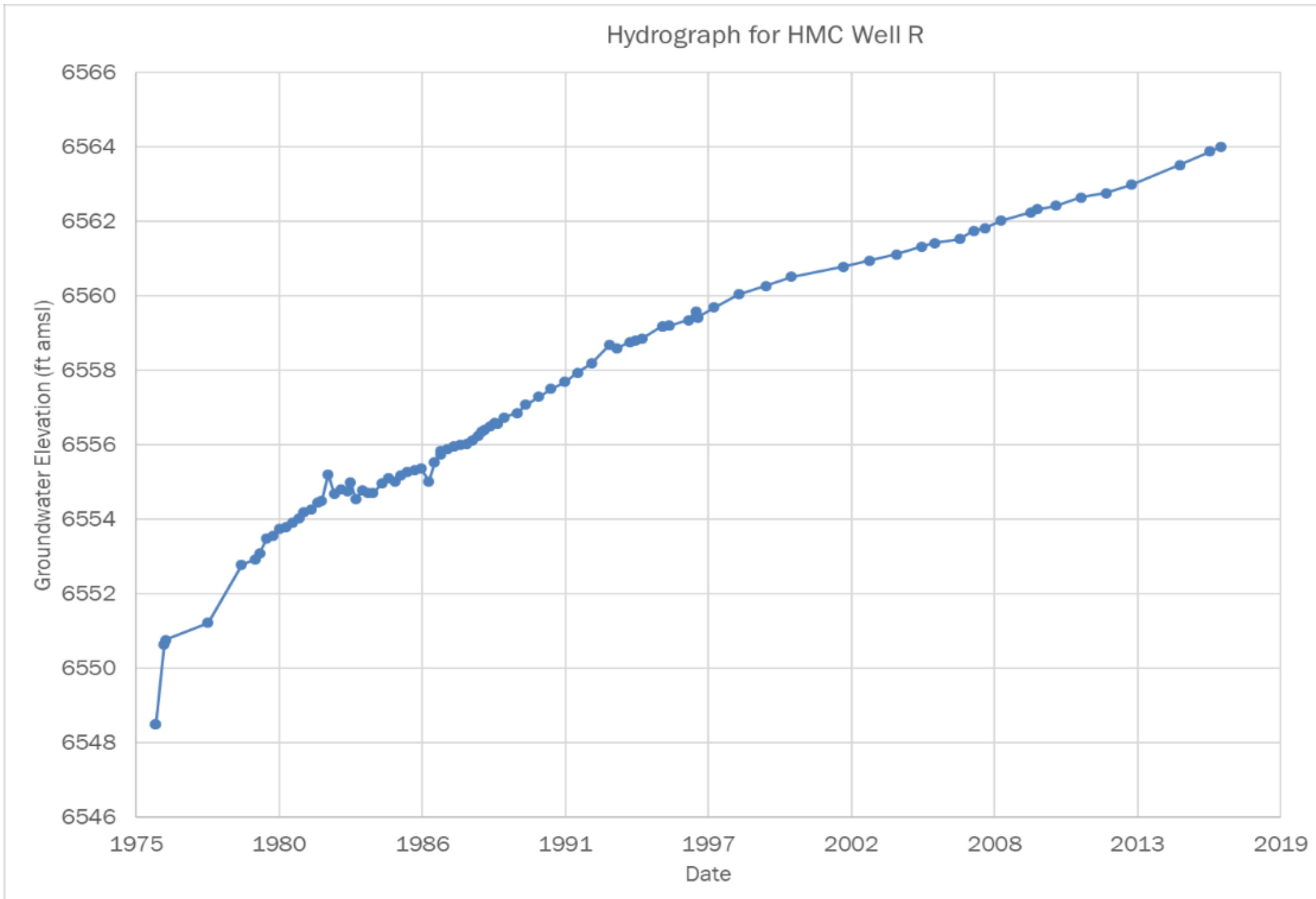


Figure 28. Hydrograph for HMC Alluvial Well R

Source: HMC 2017

2.5.2 Morrison Formation

Most uranium mining occurred in the Morrison Formation in the Ambrosia Lake area and other portions of the northern SMC Basin (Figure 1). Figure 29 presents a map of known and interpreted underground mining areas in and near Ambrosia Lake. Pumping for mine dewatering extended from 1957 into the early 1980s. Significant declines in water levels were produced to ensure dry mining conditions. Figure 30 presents hydrographs from wells and mine shafts showing water level declines up to 250 feet in the Morrison Formation during the periods of active mining (Stone et al. 1983). Estimated total pumping from the Ambrosia Lake area during the active mining period is shown on Figure 31. As shown in the figure, average annual pumping peaked near 12,500 gpm in the early 1960s, remaining above 7,500 gpm through the end of the 1970s.

Water levels in the Morrison Formation have been recovering since cessation of pumping (NMONRT 2010). Current monitoring and data sources for the Phillips and Rio Algom/Quivira Mill sites focus on alluvial groundwater and groundwater in the Mancos Shale units that subcrop beneath Arroyo del Puerto alluvium. As such, data specific to current water levels in the Morrison Formation are not readily available. BC is still researching United States Department of Energy (U.S. DOE) sources to identify water-level data in the Morrison Formation that characterize system recovery.

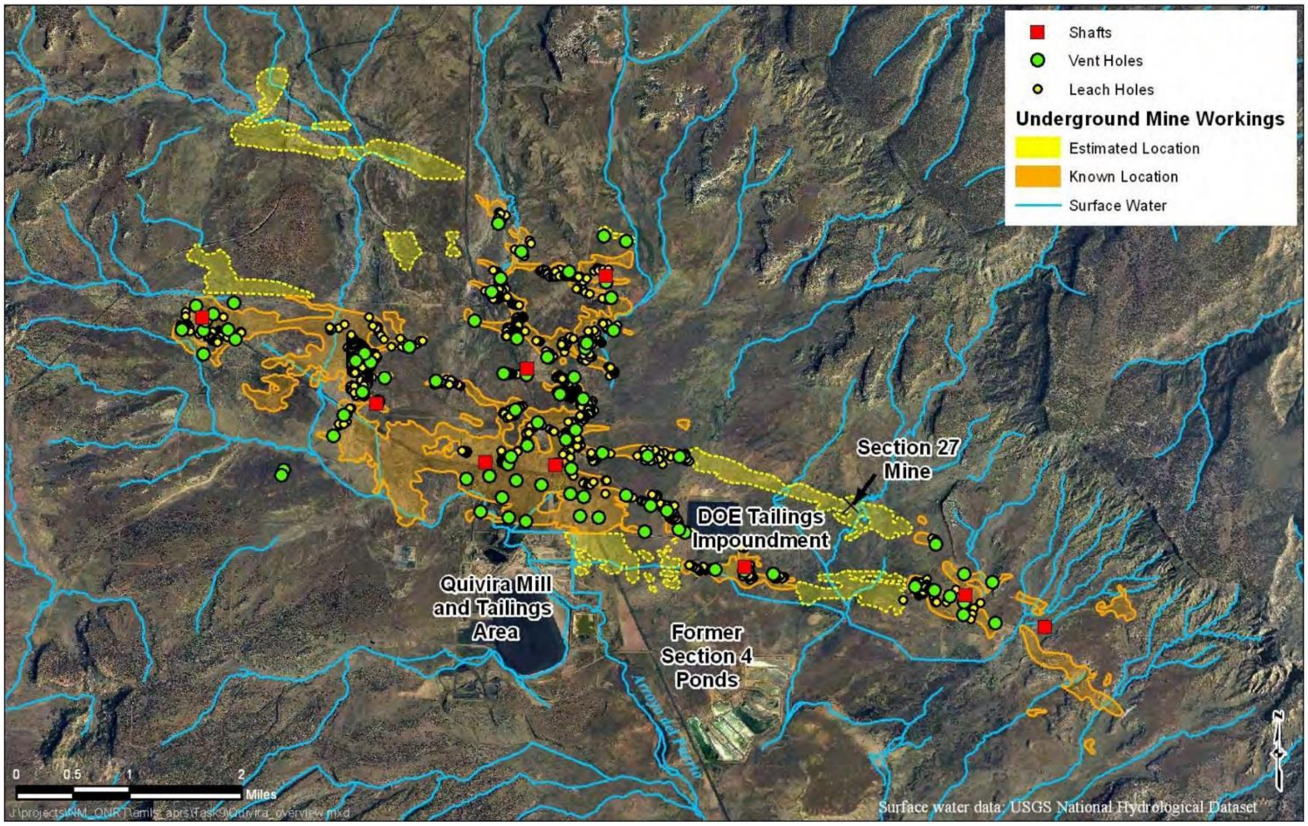


Figure 29. Map Showing Historical Mining Areas

Source: NMONRT 2010

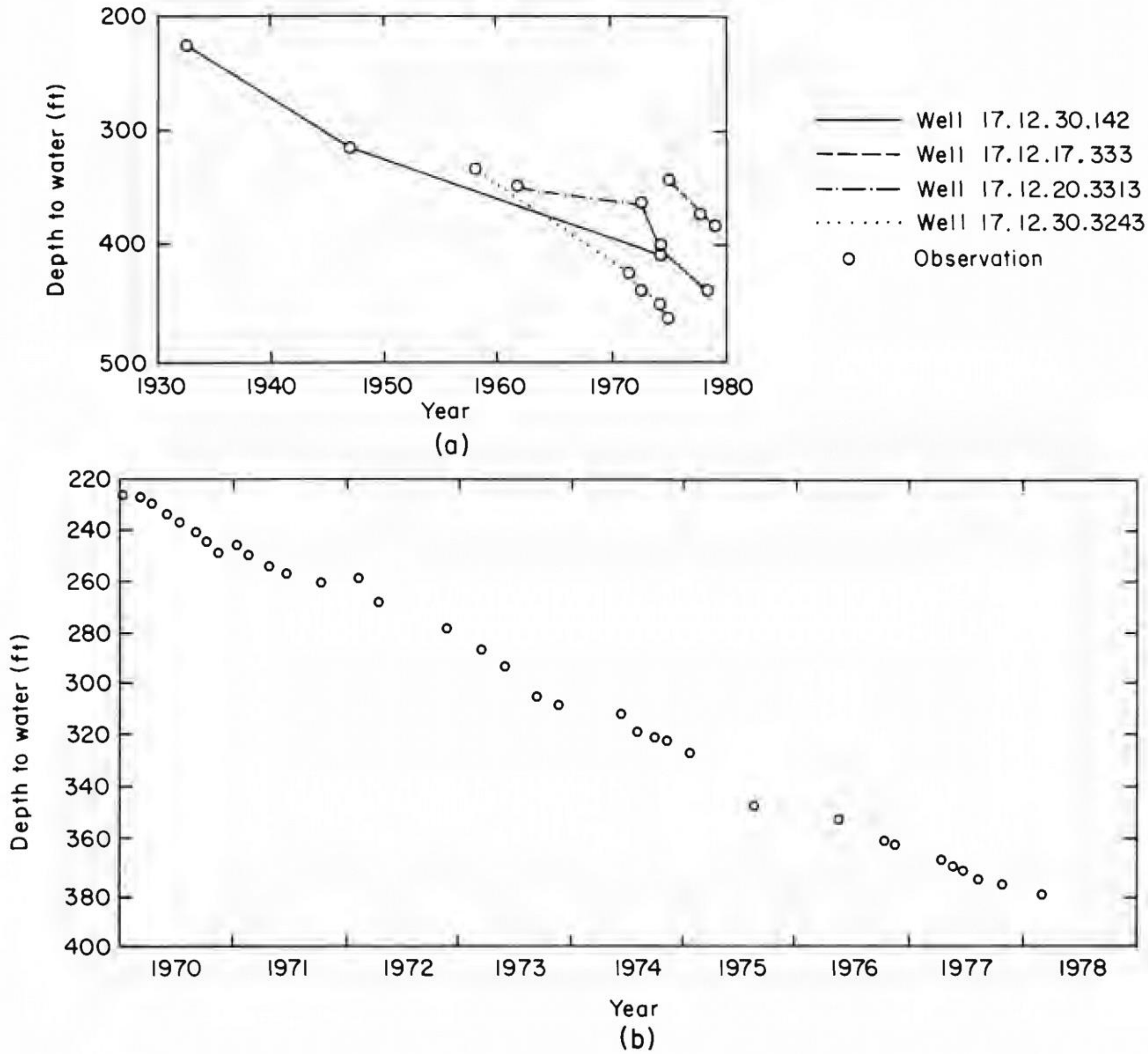


Figure 73—WATER-LEVEL DECLINES IN DAKOTA SANDSTONE AND MORRISON FORMATION.
a) Morrison Formation near Crownpoint
b) Dakota and Morrison at abandoned mine shaft (16.16.17.2141); water level in 1968 before dewatering of Church Rock mines reported at 114 ft below land surface (Hiss, 1977, p. 53).

Figure 30. Long-Term Water Level Declines from Uranium Mine Dewatering

Source: Stone et al. 1983

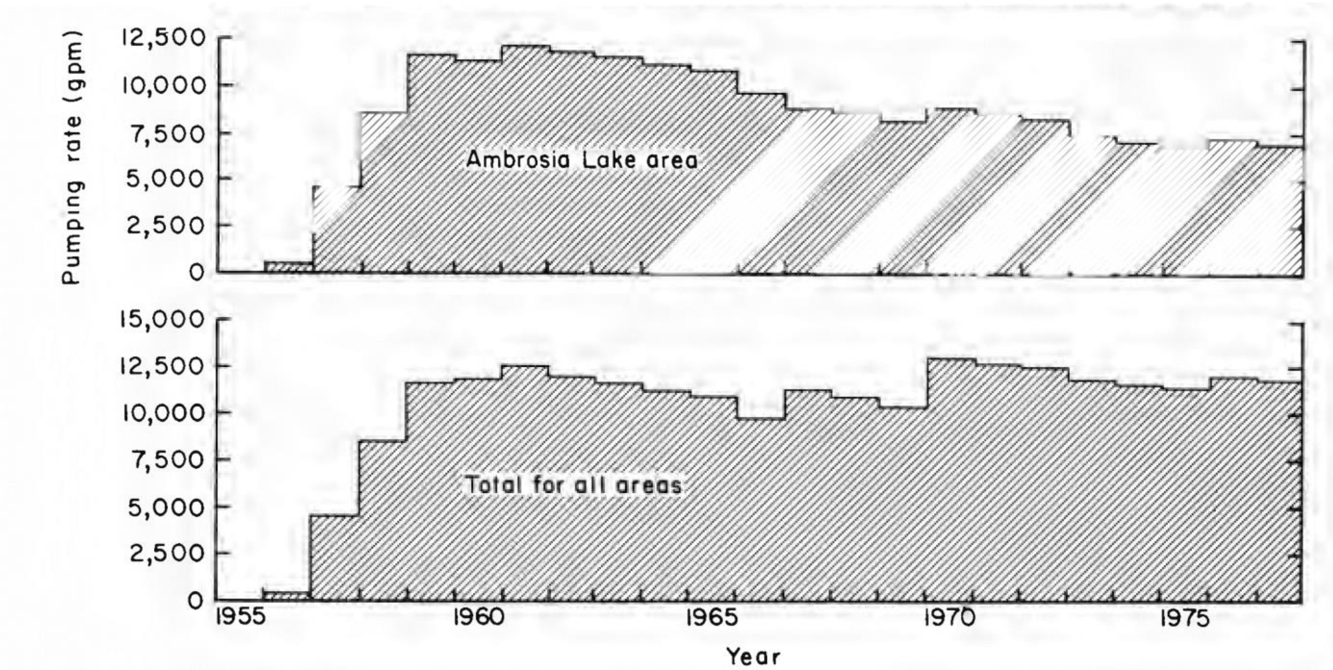


Figure 31. Estimated Pumping in Ambrosia Lake Area

Source: Stone et al. 1983

2.5.3 SAG Aquifer

The SAG aquifer represents the primary groundwater aquifer in the region surrounding Grants, and has historically been subject to significant pumping for irrigation, municipal, mining, and industrial water supplies. Long-term pumping from the aquifer has resulted in localized drawdown and changes in groundwater flow conditions (Baldwin and Anderholm 1992). Data on historical pumping for irrigation are limited. Frenzel (1992) provides estimates for irrigation pumping from the early 1900s through 1985 based on streamflow data, acres of irrigated fields, and pumping records where available. Total irrigation pumping in the Bluewater-Toldtec area was estimated to range between 3,500 acre-feet (ac-ft) in 1945 to a maximum of 12,600 ac-ft in 1954. Irrigation pumping declined to near zero after 1980 (Frenzel 1992). Figure 32 presents Frenzel's estimate of groundwater pumped for irrigation use between 1900 and 1990.

Frenzel (1992) provides tables estimating total pumping rates from municipal and industrial pumping rates through the late 1980s. Municipal pumping, primarily from the city of Grants, increased from 200 ac-ft in 1945 to more than 3,000 ac-ft in 1980. Pumping from industrial sources in the SAG aquifer, primarily from mining and uranium mills (including HMC), ranges from 75 ac-ft in 1952 to a peak of 2,500 ac-ft in 1957. Figure 33 presents graphs showing municipal and industrial pumping from the SAG aquifer through the late 1980s (Frenzel 1992). BC is currently working on gathering more recent data related to pumping from the SAG aquifer.

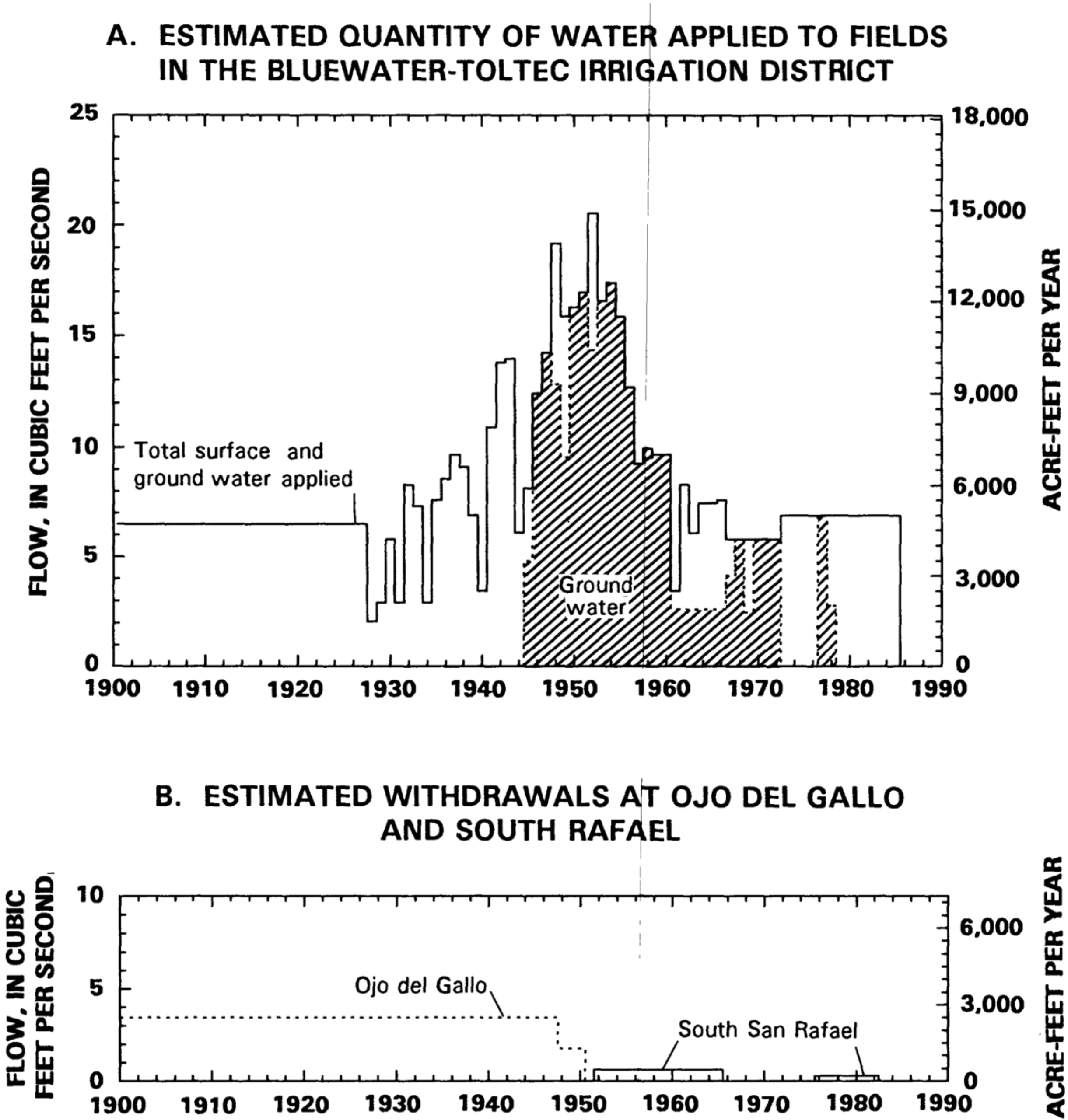


Figure 32. Estimated Irrigation Pumping in the SAG Aquifer

Source: Frenzel 1992

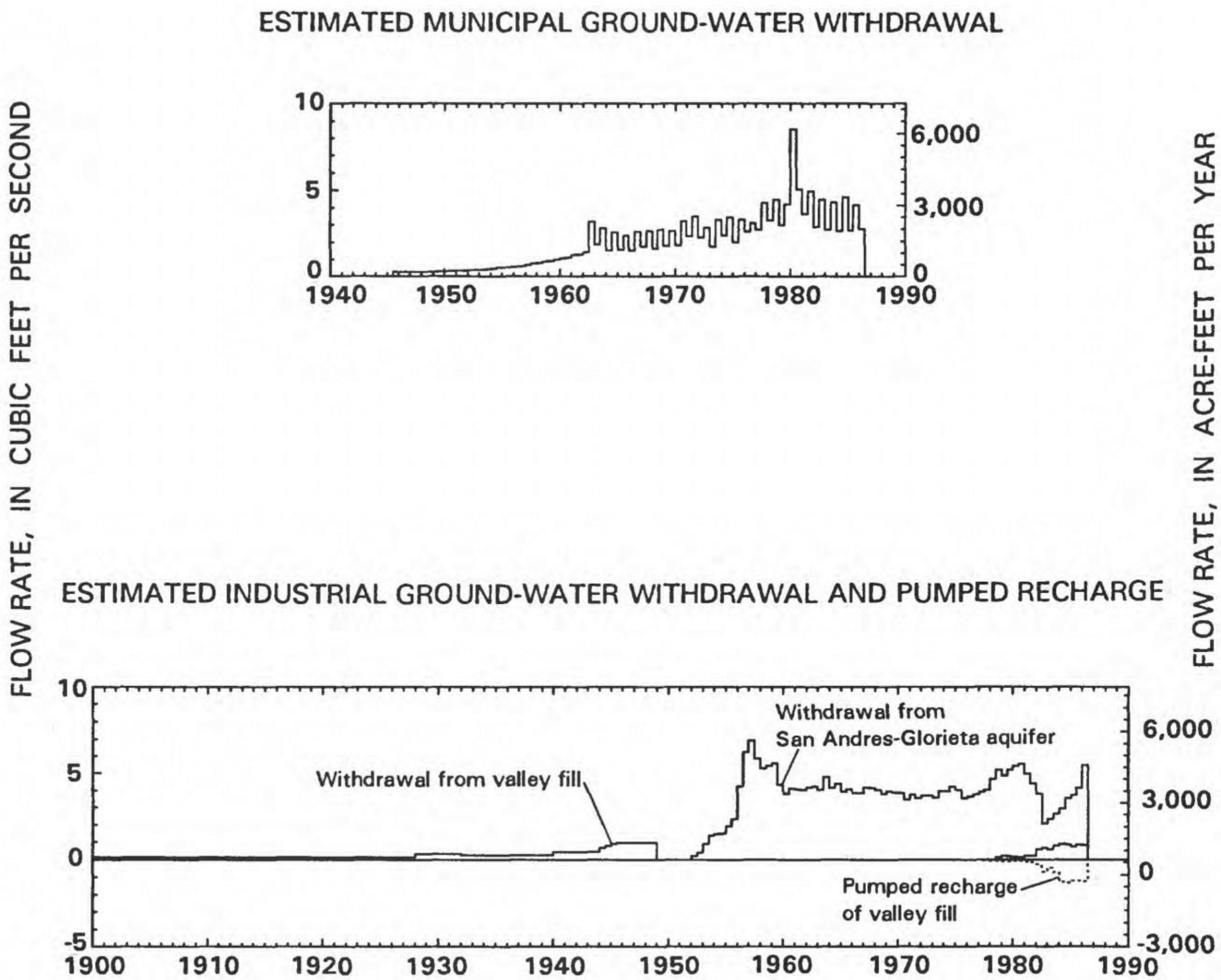


Figure 33. Estimated Municipal and Industrial Pumping in the SAG Aquifer

Source: Frenzel 1992

2.6 Effects of Geologic Structure on Groundwater Flow

Groundwater flow in the SMC Basin is likely influenced by both stratigraphic variations and local- and regional-scale faulting and other structures. In general, groundwater flows in response to variations in hydraulic head (hydraulic gradients). Inter-aquifer movement of water (leakage) likely occurs in the San Juan Basin based on regionally observed head differences between aquifers (Stone et al. 1983). Downward leakage through intervening units may occur when the hydraulic gradient is vertically downward, which occurs near recharge areas along unit outcrops. Conversely, upward leakage can occur when hydraulic gradients are upward between units, as occurs in the central part of the San Juan Basin where artesian heads are observed. In the vicinity of the SMC Basin, vertical leakage between aquifer units is likely limited by the presence of low-permeability shale and other fine-grained units. Langman et al. (2012) note that both the Mancos Shale and Chinle Formation likely act as aquitards between aquifers at the basin scale. Stone et al. (1983) note that observed head differences of up to 200 feet between the Dakota Sandstone and Morrison Formation in the SMC Basin are suggestive of limited vertical leakage between these two units. Vertical movement from alluvium into underlying bedrock units has been observed in detailed data collected at each of the historical mill sites in the SMC Basin.

Regional fault structures have been shown to have a significant impact on groundwater flow, at least at local scales. Regional normal faults can inhibit flow by disconnecting permeable pathways or reducing porosity from fault gouge, but faults can also increase permeability along and adjacent to the fault trace because of brecciation and allow for vertical movement between aquifers (Langman et al. 2012). The primary regional geologic structures mapped in the SMC Basin are shown on Figure 34. Most faults strike north to northeast. High-angle normal faulting has resulted in vertical displacements that have offset aquifer flow units, although some faults have a strike slip (horizontal) component of slip. The large northeast-striking San Mateo normal fault in the central portion of the SMC Basin has vertical displacements of up to 450 feet (HDR 2016). However, Brod and Stone (1981) state that these displacements along the San Mateo Fault have not significantly influenced groundwater elevations in the Morrison Formation in the Ambrosia Lake area, as shown on Figure 35.

Faulting in the SAG aquifer has been interpreted to affect lateral groundwater flow. The Big Draw and San Rafael faults have been interpreted as restrictions to groundwater flow (Frenzel 1992). Figure 36 presents a conceptual schematic showing the influence of the San Rafael Fault near Ojo del Gallo, forcing water upward into local alluvium.

Local-scale faulting at the Bluewater Mill site has been observed to affect groundwater flow (U.S. DOE 1997). A major east-west trending fault with displacements between 300 and 400 feet is located just east of the main tailings pile at the site. This is illustrated on Figures 37 and 38, which present three-dimensional renderings of fault offsets at the Bluewater Mill site. The San Andres Limestone is juxtaposed against the Chinle Formation, which acts to restrict groundwater flow (U.S. DOE 1997 and 2014).

Faults have also been shown to restrict groundwater flow in the Chinle Formation at the HMC Mill site. Two faults, referred to as the West and East faults, bound the large tailings pile at the site (Figure 39). The two faults are approximately vertical with the downthrown side to the east (HDR 2016). In general, structural offset of the Chinle Formation from these faults has resulted in the juxtaposition of permeable sandstones with lower-permeability mudstones and siltstones. Water-level data collected at the site suggest that these faults act to significantly restrict groundwater in sandstone units in the Chinle (as discussed in Section 3.2). These faults are not extensive and do not affect flow in the underlying SAG aquifer, most likely because the fault offset is much less than the vertical thickness of the aquifer (HDR 2016). Figure 40 provides a cross section of fault offsets at the HMC Mill site.

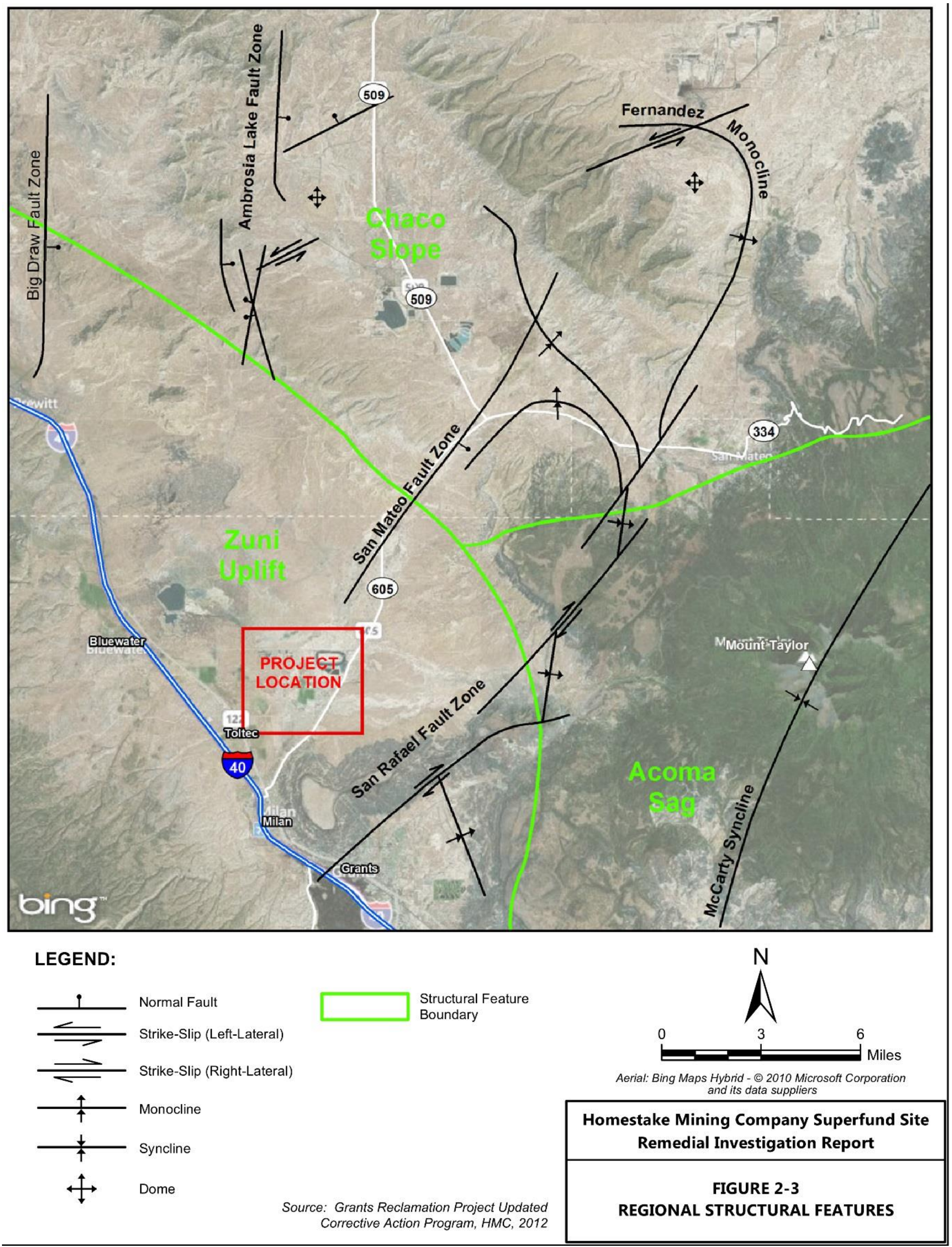


Figure 34. Primary Geologic Structures in the San Mateo Creek Basin

Source: HDR 2016

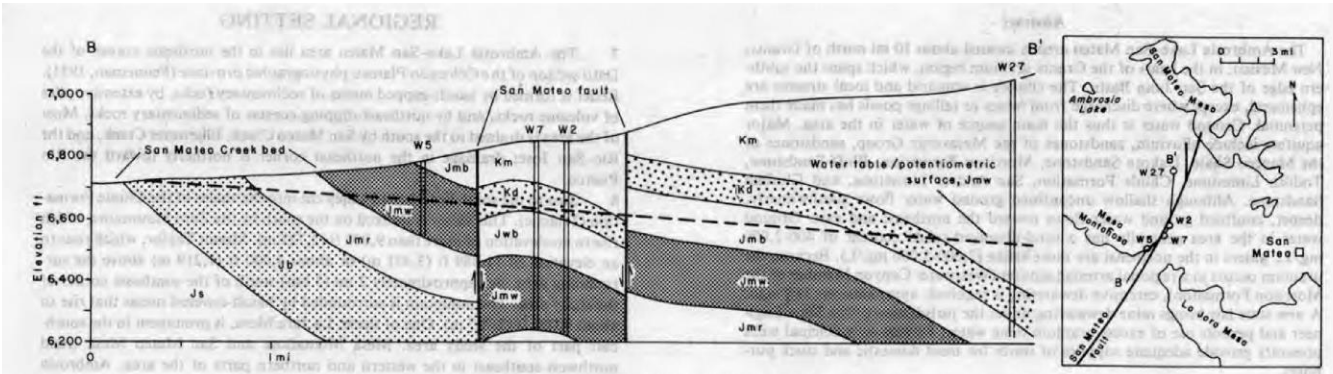


Figure 35. Cross section through the San Mateo Fault: Ambrosia Lake

Source: Brod and Stone 1981

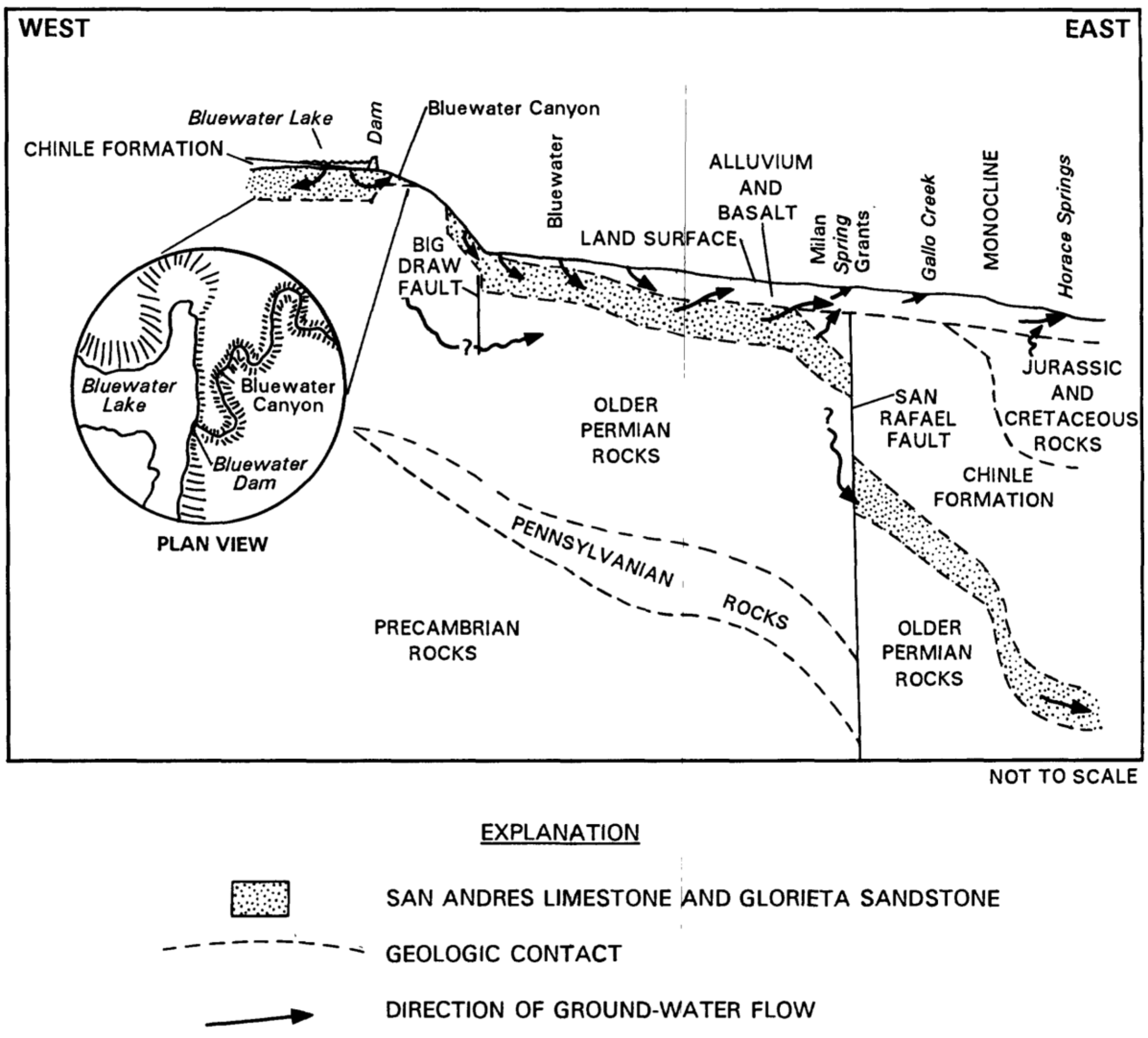


Figure 36. Influence of San Rafael Fault on Groundwater Flow: SAG Aquifer

Source: Frenzel 1992

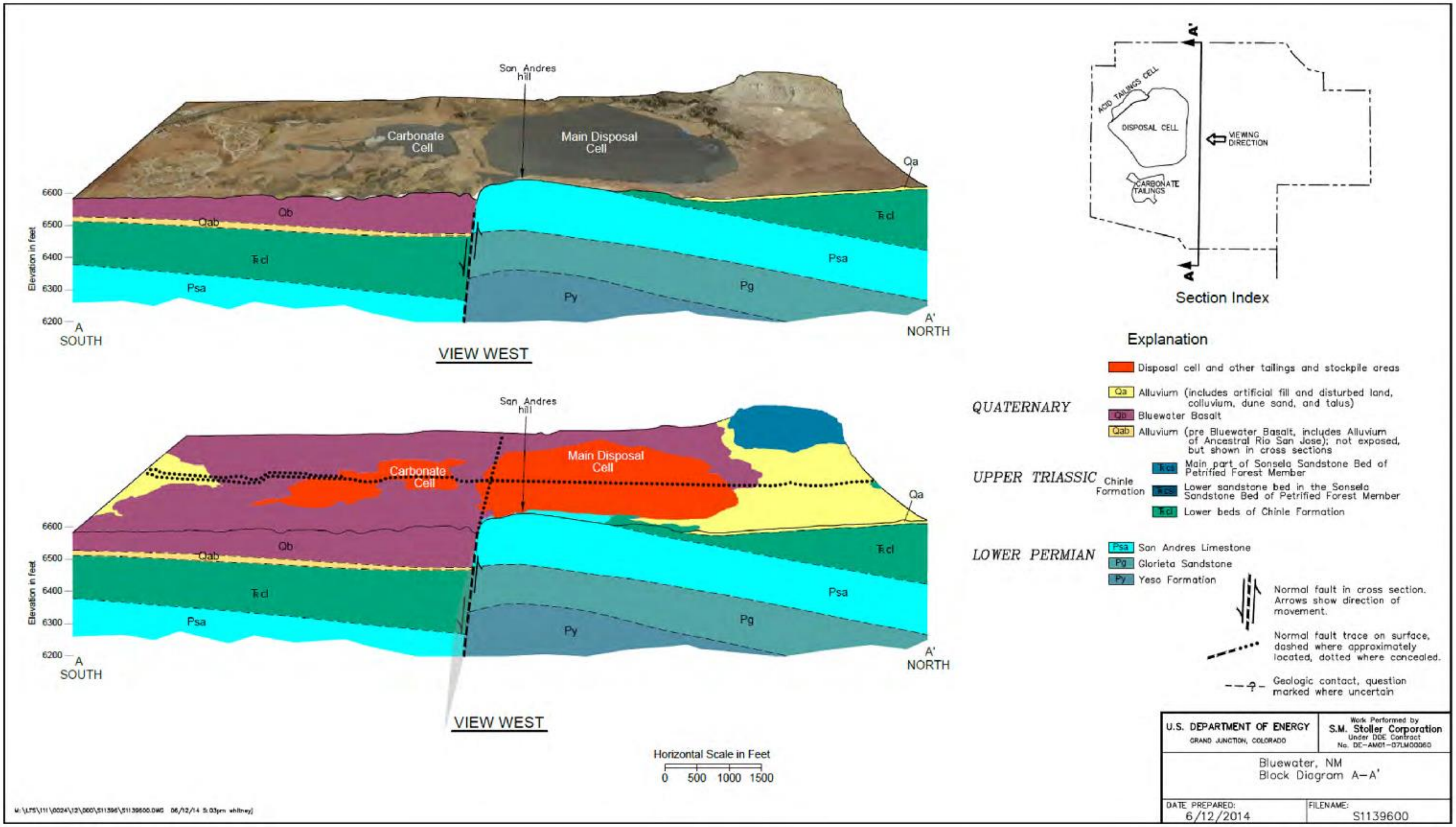


Figure 37. Fault offsets at Bluewater Mill (1)

Source: U.S. DOE 2014

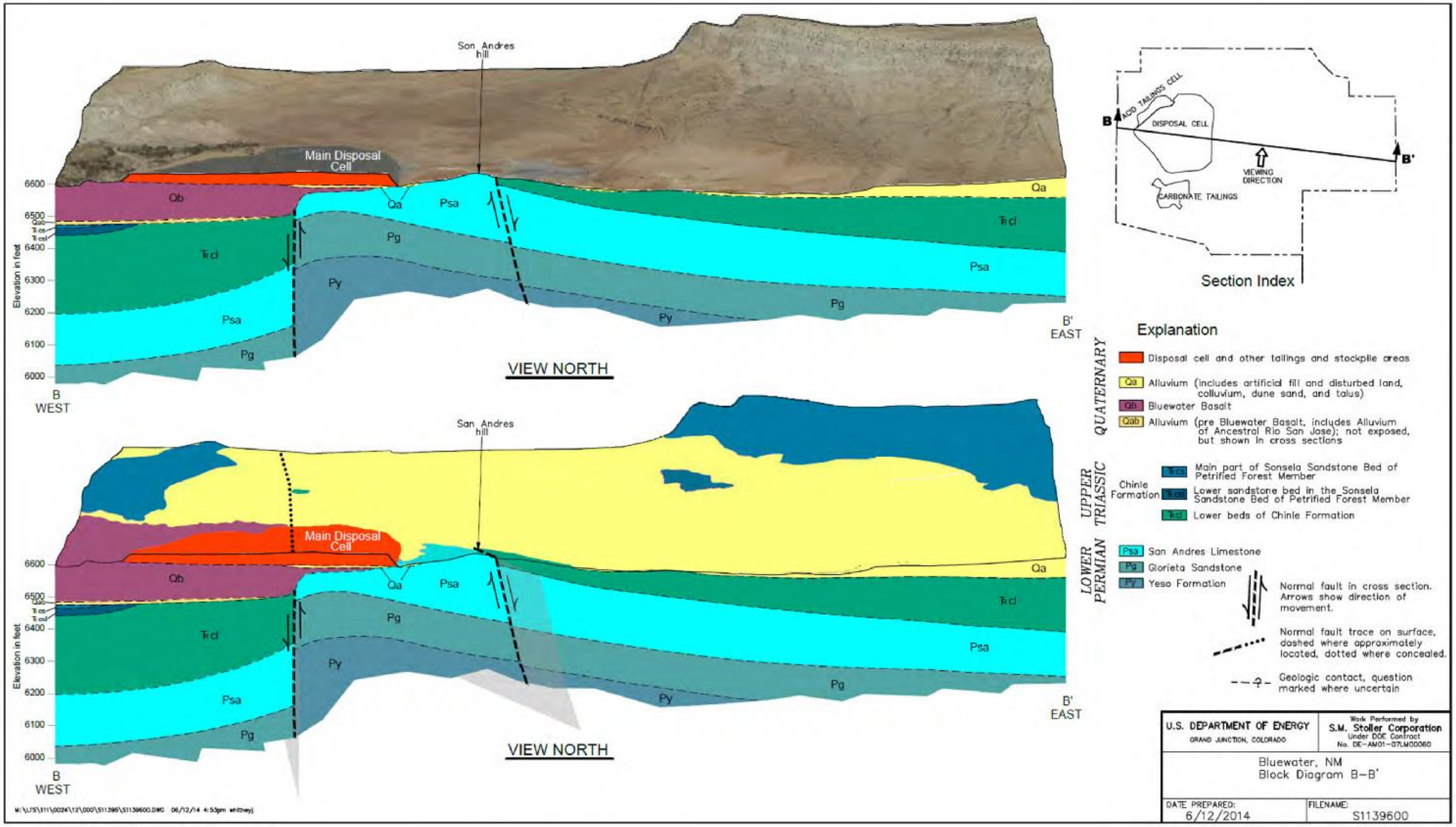


Figure 38. Fault Offsets at Blue Mill (2)

Source: U.S. DOE 2014

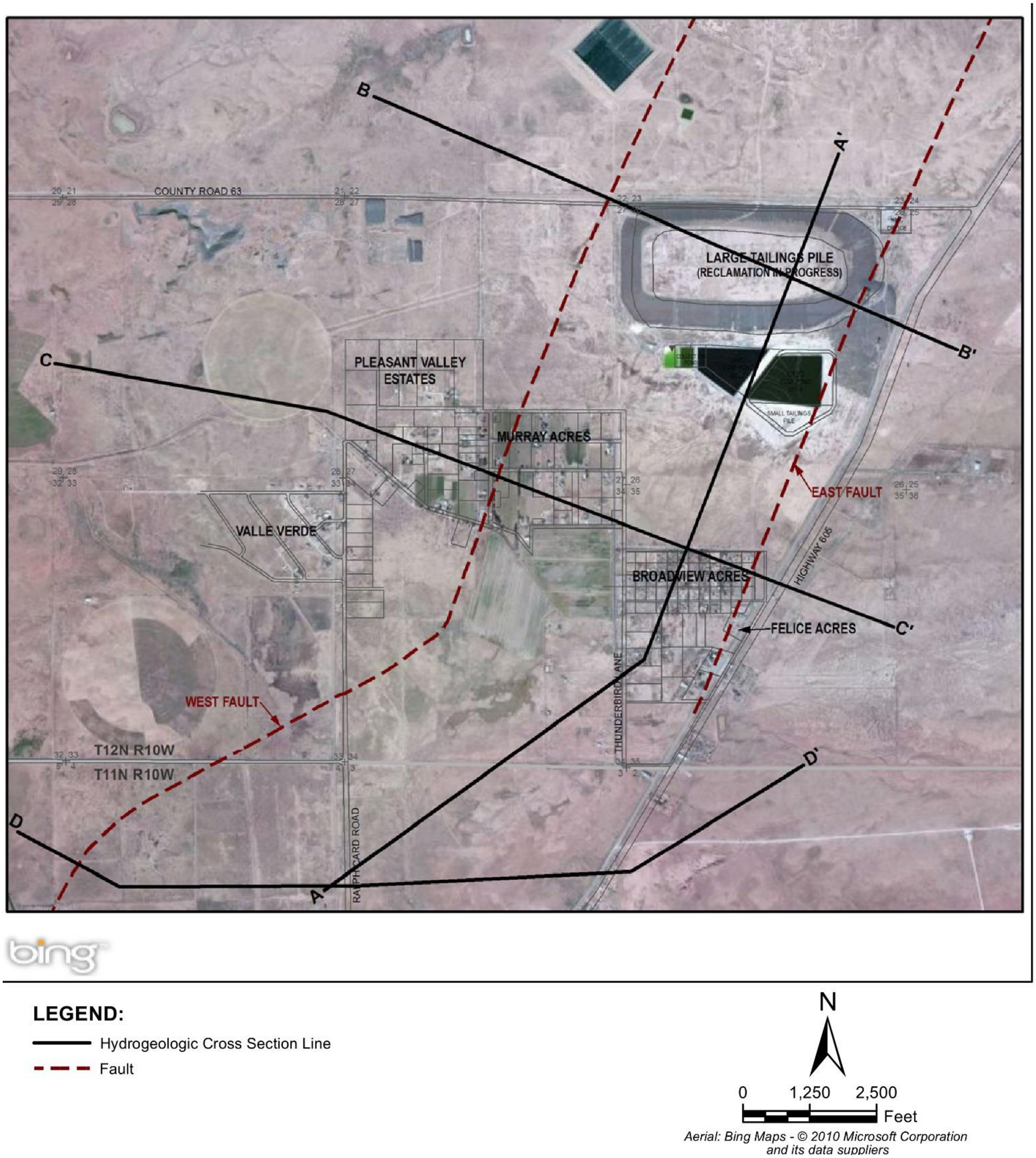


Figure 39. Faults Mapped at HMC Mill Site

Source: HDR 2016

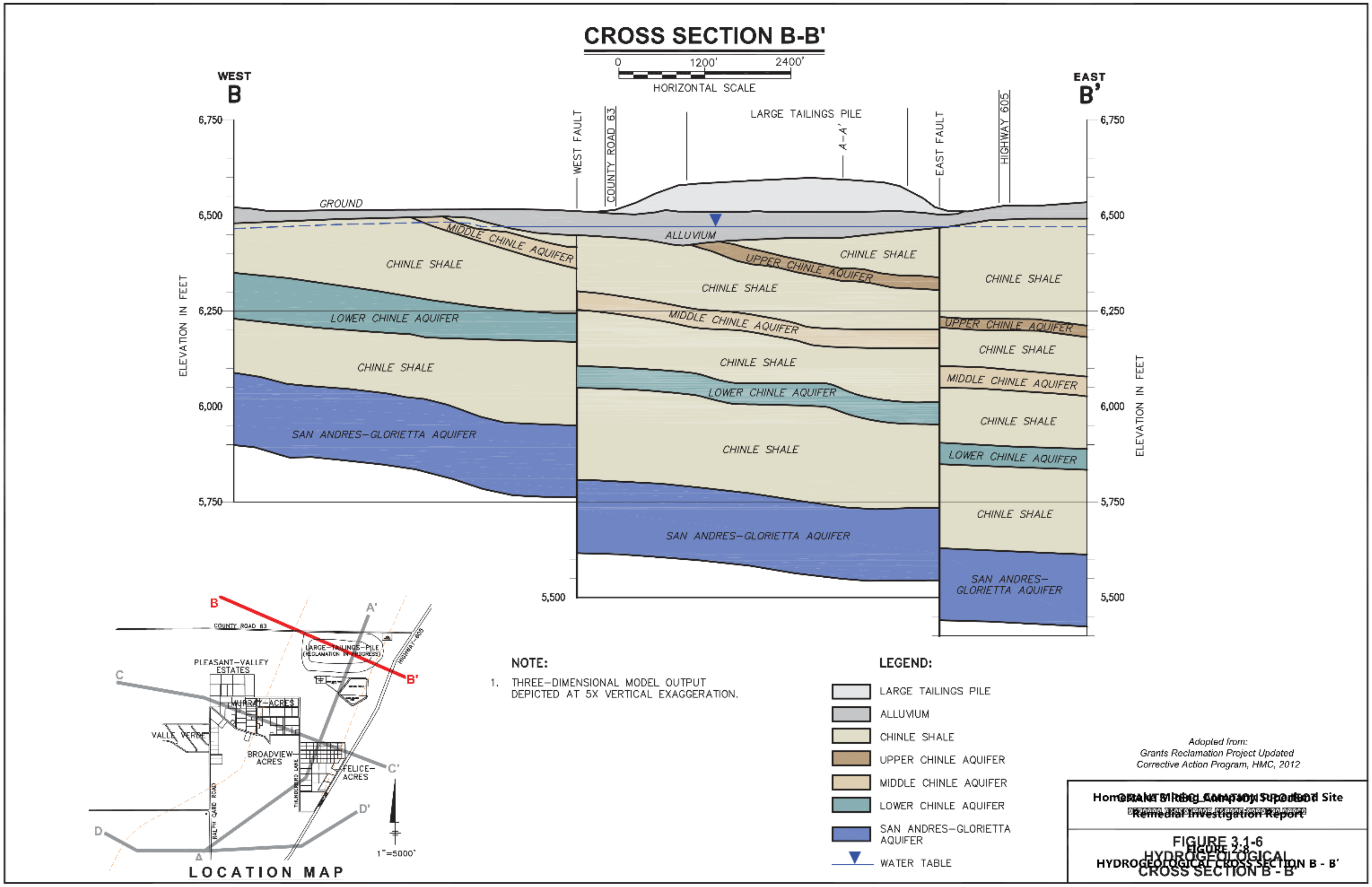


Figure 40. Cross Section B-B[1] Showing Fault Offsets at HMC Mill Site

Source: HDR 2016

2.7 Regional Water Quality

Mining activities have affected groundwater quality in alluvium and bedrock aquifers in the vicinity of the four mill sites. In the Ambrosia Lake area, direct discharge and surface infiltration of mine dewatering flows and from unlined evaporation ponds has resulted in elevated concentrations of constituents in alluvial groundwater, including sulfate, uranium, radium, gross alpha emissions, total dissolved solids (TDS), and selenium (U.S. EPA 2016). Concentrations of these constituents have exceeded federal drinking water standards in both alluvial groundwater and within underlying bedrock units downgradient of historical mining and mill sites in the Ambrosia Lake area.

Activities at the Bluewater Mill site affected groundwater within both alluvium associated with the Rio San Jose and the underlying SAG aquifer (U.S. DOE 2014). Elevated levels of molybdenum, selenium, and uranium have been detected downgradient of the Bluewater Mill site and historical tailings pond. Uranium has been identified as the primary constituent of concern, and uranium concentrations above the federal drinking water standard have been observed downgradient of the site.

Groundwater quality at the HMC Mill site is discussed in detail in Section 3.4.

2.8 Regional HSCM Summary

Key elements of the Regional HSCM for the SMC Basin are summarized as follows:

- The SMC Basin is located at the southern margin of the San Juan Basin.
- Aquifers of Quaternary, Cretaceous, Jurassic, and Permian age units are present in the SMC Basin.
- Principal regional aquifers that may have significant flow in the SMC Basin include the alluvium, Menefee, Point Lookout, Gallup, Morrison, and SAG aquifers.
- Geologic uplift of the Zuni Mountains on the southwest edge of the SMC Basin has exposed outcrops of the principal aquifers. Aquifer units generally dip to the north-northeast toward the central portion of the San Juan Basin.
- Flow directions in the Cretaceous and Jurassic aquifers are variable but generally toward the east-northeast from outcrops and subcrops in the SMC Basin toward discharge to the Rio Puerco watershed.
- Groundwater flow in the Permian SAG aquifer is generally to the east, with local discharge via upward flow to alluvium of the Rio San Jose.
- Hydraulic conductivities and other aquifer parameters typically vary greatly between units, vertically within many units, and even areally within some units in the basin.
- Historical groundwater pumping has occurred primarily in the alluvium, Morrison, and SAG aquifers.
- Extensive pumping from the Morrison Formation in the Ambrosia Lake area between the late 1950s and early 1980s resulted in significant water level declines in the aquifer. Water levels in this area are recovering after the cessation of pumping, but few water-level data are available to evaluate system recovery.
- Groundwater pumped from the Morrison Formation for dewatering of uranium mines was discharged into local drainages including Arroyo del Puerto. This discharge provided significant recharge to previously unsaturated alluvium, and this water still persists in the alluvial system.
- The SAG aquifer represents the primary regional source of groundwater. Extensive pumping from the aquifer has occurred since the 1940s for irrigation, municipal, and industrial uses.
- Long-term pumping in the SAG aquifer has produced local-scale and regional-scale drawdowns in the aquifer.
- In general, there is little evidence of inter-aquifer flow in the basin, which is due to the presence of low-permeability aquitards between the principal aquifers.

- High-angle normal faulting has locally affected groundwater flow, including near the Bluewater and HMC Mill sites, where local faulting has been shown to restrict groundwater flow.
- Mining and milling activities within the SMC Basin have impacted both local- and regional-scale groundwater quality.

Section 3: Site HSCM

As previously mentioned, the HMC Mill site lies in the southernmost (lower) portion of the SMC Basin (Figure 1). The site is located adjacent to lower SMC and State Highway 605. Uranium ore from the Grants Mineral Belt was processed at the site from 1958–90 (HDR 2016). The site currently consists of partially reclaimed tailings piles, buried (i.e., reclaimed) mill debris, and wells and evaporation ponds related to ongoing active groundwater restoration that are shown in Figure 41 (HDR 2016).

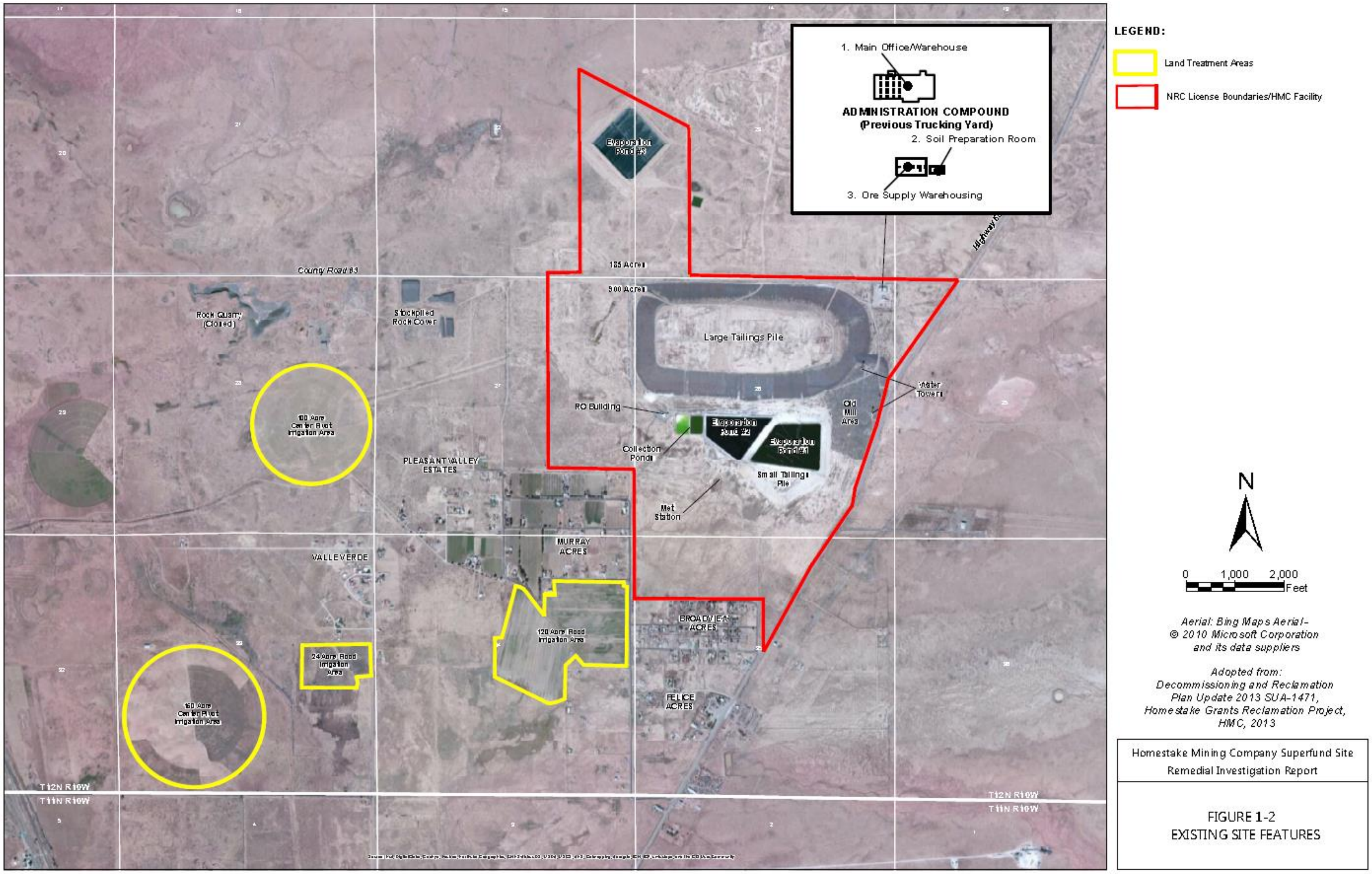


Figure 41. HMC Mill Site Facilities

Source: HDR 2016

3.1 Site Geology

The following four geologic units discussed in the Regional HSCM (Section 2) are present at the HMC Mill site:

- Alluvium
- Chinle Formation
- San Andres Limestone
- Glorieta Sandstone

Quaternary alluvium underlies the entire site (Figure 5) and is generally 50 to 100 feet thick, as shown in the north-south cross section in Figure 43.

The Chinle Formation is up to 900 feet thick at the site, as shown in Figure 40. Although the Chinle is dominated by low-permeability shale units, beneath the site it contains three water-bearing units of relatively higher permeability. These water-bearing units are referred to as the Upper Chinle Sandstone, Middle Chinle Sandstone, and Lower Chinle Mudstone; the latter is reported to be a horizon of higher permeability mudstone resulting from the development of secondary permeability (HDR 2016).

The lowermost units of interest at the site are the San Andres Limestone and Glorieta Sandstone, which together are 200 to 225 feet thick. As mentioned in Section 2, the SAG is overlain by an unconformity and underlain by the lower-permeability Yeso and Abo formations.

The sedimentary rock units at the site dip gently to the east-northeast, following the regional dip of these units (Figure 43). Erosion has caused the sedimentary rock units to subcrop beneath the alluvium at the site, as shown on Figures 42 and 43.

Two north-northeast-trending normal faults are present at the site, known as the East Fault and West Fault (Figures 39 and 40, respectively). The faults are approximately vertical and down-dropped on the east (HDR 2016). The vertical displacements of the faults have juxtaposed the more permeable units of the Chinle Formation against less permeable mudstone layers (Figure 40). The San Andres Limestone and Glorieta Sandstone, although vertically displaced, maintain horizontal connectivity across the faults (Figure 40). The East Fault terminates approximately 1 mile south of the tailings piles (Figure 39).

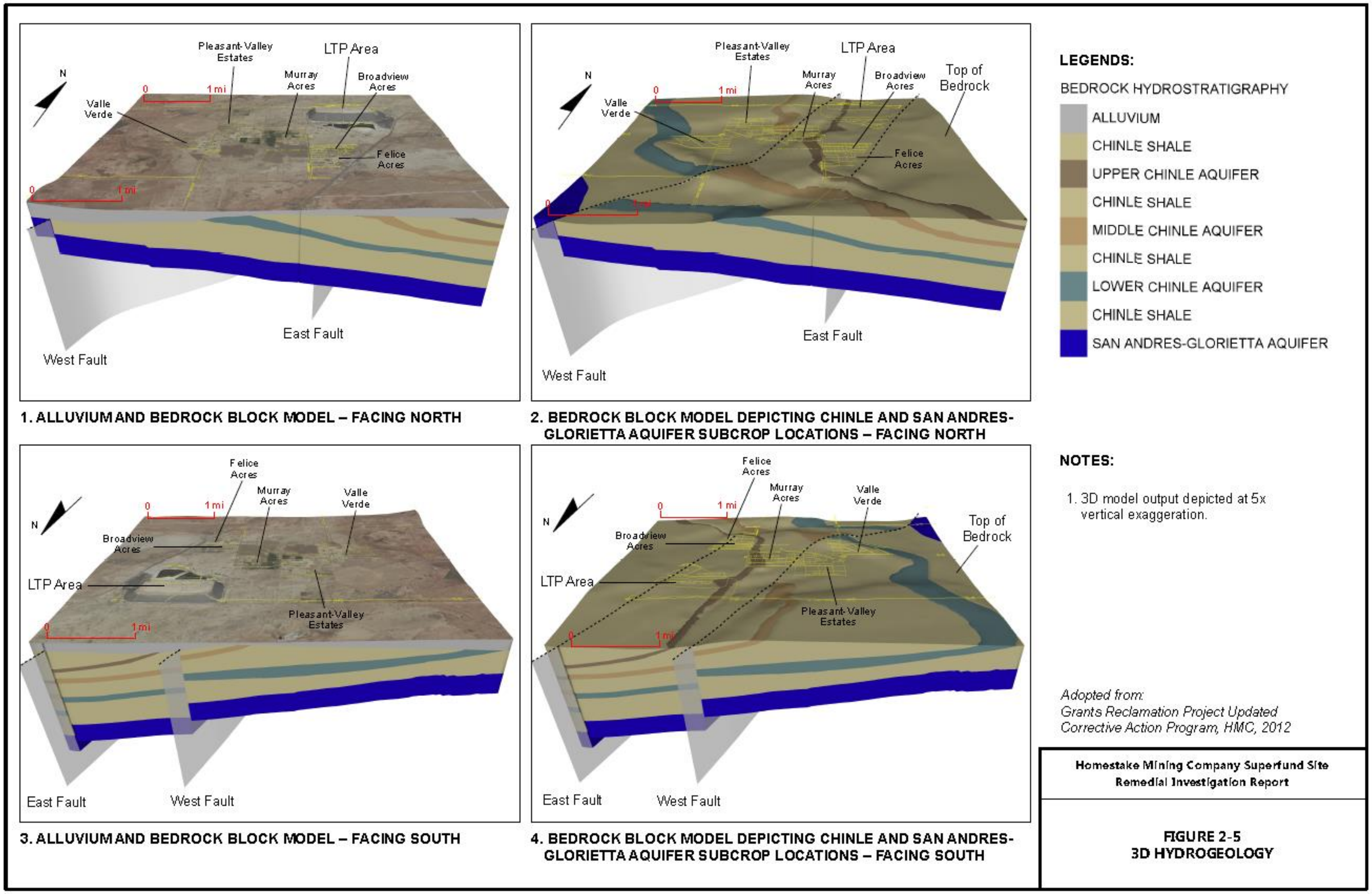


Figure 42. HMC Mill Site Geology

Source: HDR 2016

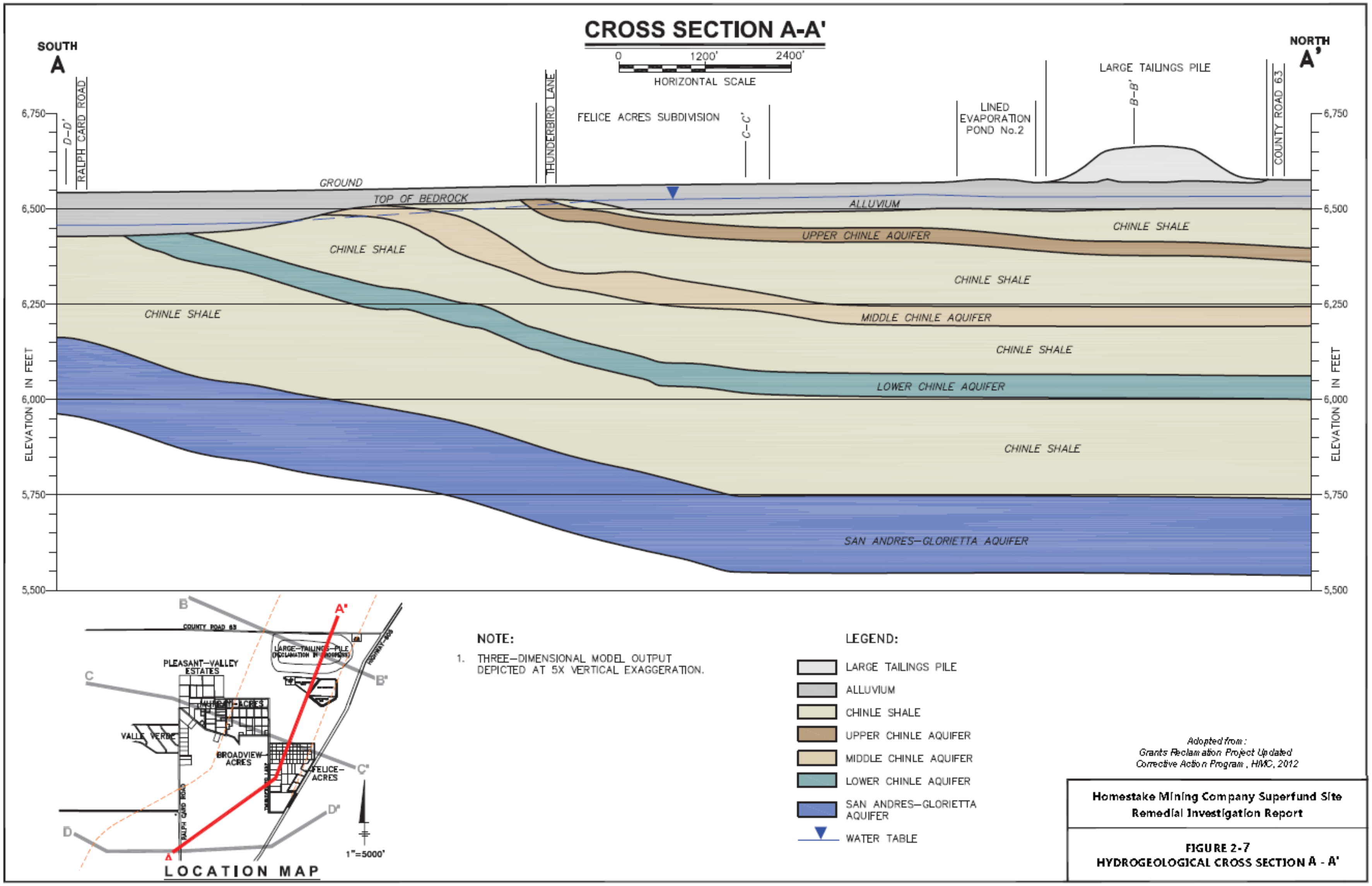


Figure 43. Local Dip at HMC Mill Site

Source: HDR 2016

3.2 Site Hydrostratigraphic Units and Aquifers

The alluvium, three water-bearing horizons in the Chinle Formation (Upper, Middle, and Lower), and SAG aquifer are the principal water-bearing units at the HMC Mill site.

3.2.1 Alluvial Aquifer

The saturated extent of the alluvial aquifer at the site is shown on Figure 44. The alluvial aquifer is unconfined with saturated thickness ranging from zero to approximately 70 feet. Depth to groundwater ranges from 40 to 60 feet below ground surface (HDR 2016). The alluvial aquifer is composed of three distinct but connected alluvial systems: SMC, Rio Lobo, and Rio San Jose (HDR 2016). The SMC alluvium composes the north/northeastern branch and the central portion of the alluvial aquifer beneath the site, the Rio Lobo alluvium forms the eastern/southeastern branch of the alluvial aquifer, and the Rio San Jose alluvium forms the west-southwest portion of the alluvial aquifer on Figure 44. A local bedrock high causes the alluvial aquifer to branch to the west and south before the SMC and Rio Lobo alluvial systems converge with the Rio San Jose alluvium.

Hydraulic properties of the alluvial aquifer have been extensively characterized by drilling and well installation at the site. The SMC and Rio Lobo alluvium are derived from similar parent materials and have been characterized as very fine to coarse sand with relatively small and discontinuous silt and clay lenses (HDR 2016). Hydraulic conductivity of the SMC and Rio Lobo systems is relatively high, ranging from 10 to more than 200 feet per day (ft/d) (HDR 2016). The highest hydraulic conductivity values have been measured in a paleochannel directly west and southwest of the Large Tailings Pile (U.S. DOE 2014) (Figure 44). In other areas, hydraulic conductivity of the alluvial aquifer typically ranges from 10 to 70 ft/d (U.S. DOE 2014). Specific yield generally ranges from 0.038 to 0.280 (HDR 2016).

Although not directly underlying the HMC Mill site, the Rio San Jose alluvium consists of coarser materials (i.e., higher-energy sand and gravel deposits) compared to the SMC and Rio Lobo alluvium (HDR 2016; U.S. DOE 2014). Hydraulic properties of the Rio San Jose alluvium have been characterized approximately 3 miles upstream at the Bluewater Mill site (U.S. DOE 2014). Hydraulic conductivity in the Rio San Jose alluvium at the Bluewater Mill site ranges from 75 to 100 ft/d, and specific yield ranges from 0.10 to 0.25 (U.S. DOE 2014).

West of the HMC Mill site, the alluvial aquifer contains a small interbedded Quaternary basalt flow to the west of Pleasant Valley Estates (Figure 45). Although this local basalt has not been characterized, basalt flows at the Bluewater Mill site were discussed by U.S. DOE (2014). Groundwater has the potential to flow horizontally in both the basalt and alluvium where alluvial groundwater heads are higher than the base of the basalt and where the basalt is relatively permeable because of fractures. Where the permeability of the basalt is low, it tends to act as a local confining layer for the underlying alluvial aquifer.

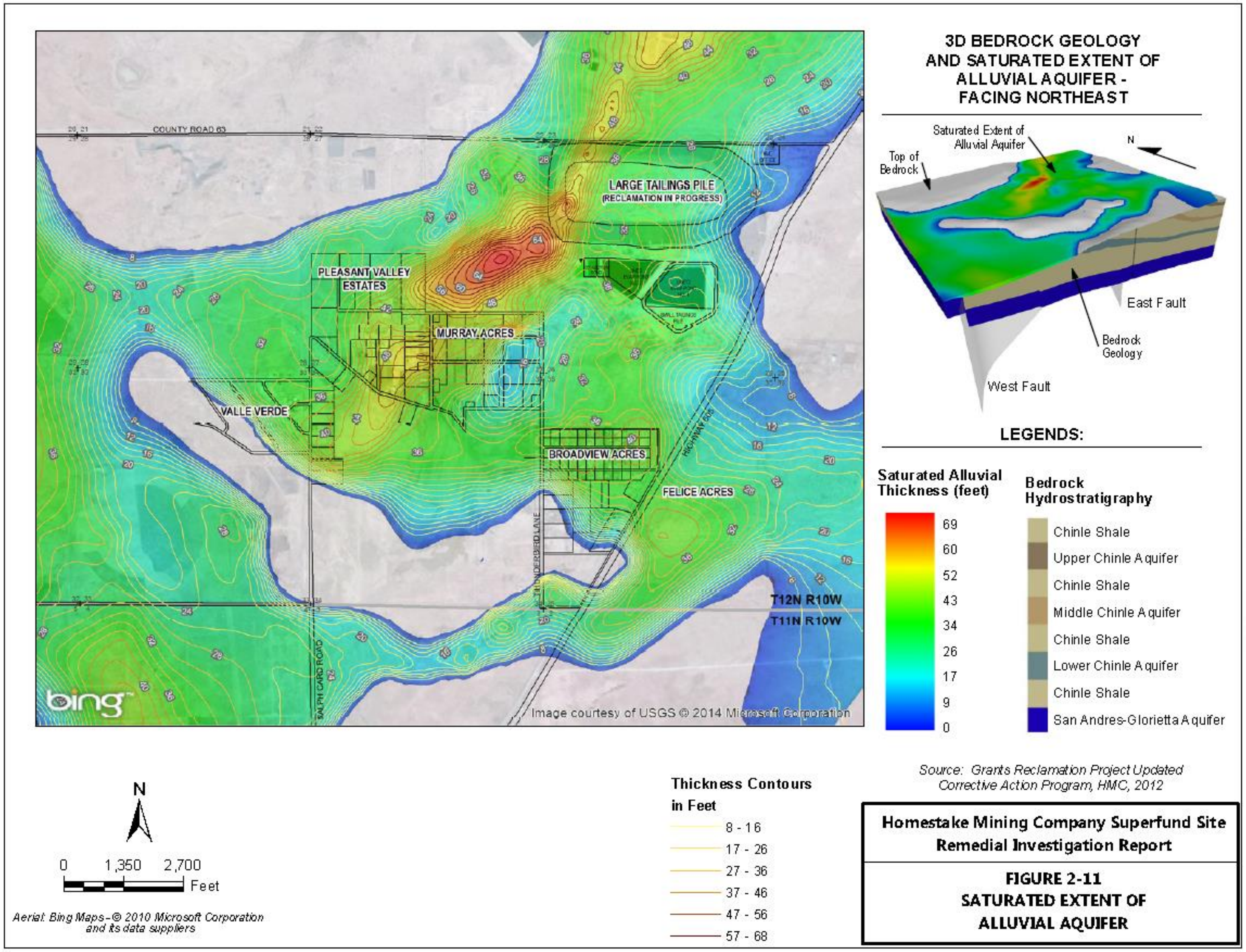


Figure 44. Saturated Extent of the Alluvial Aquifer

Source: HDR 2016

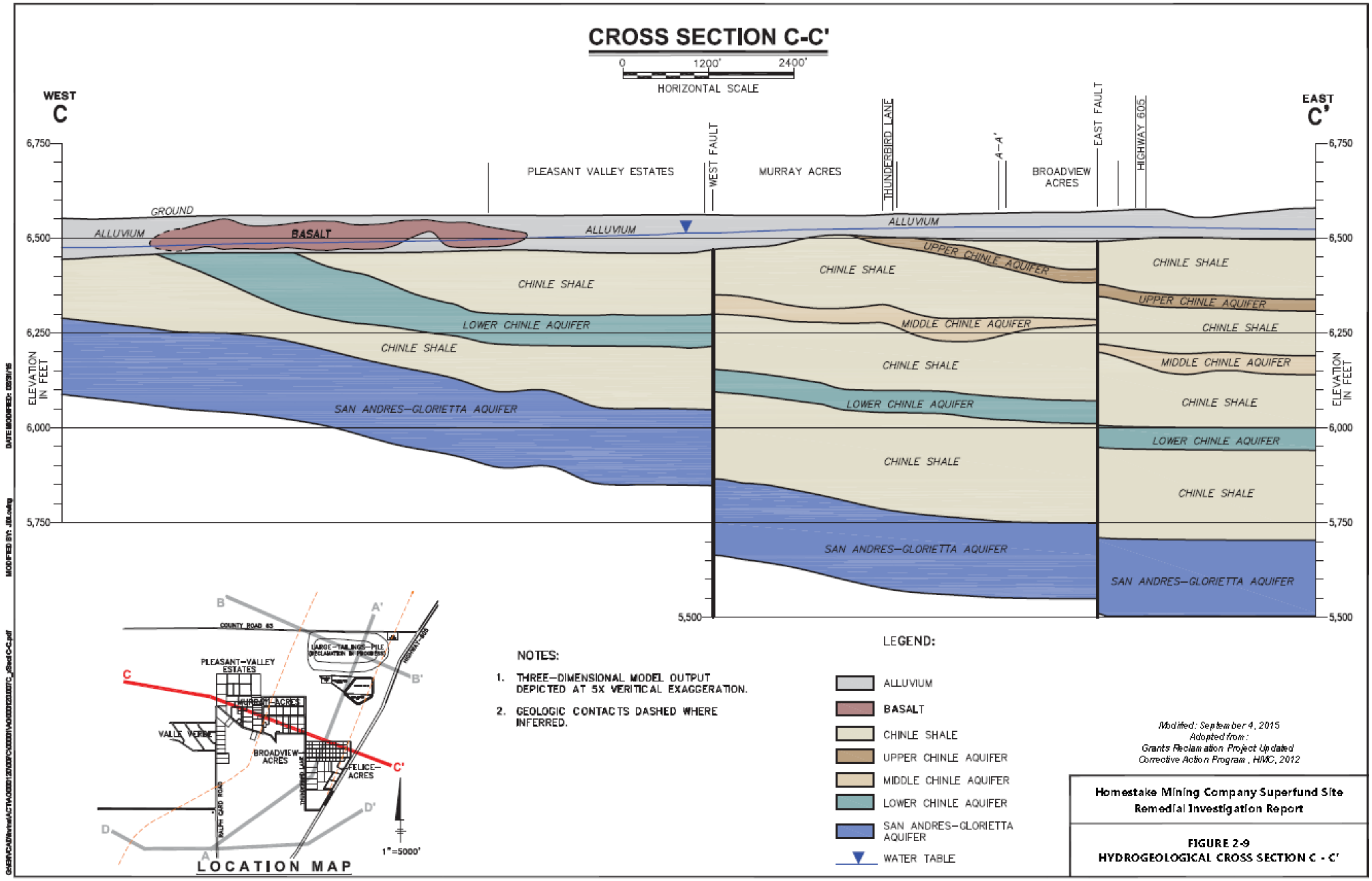


Figure 45. Cross Section Sshowing Interbedded Quaternary Basalt Flow

Source: HDR 2016

3.2.2 Chinle Formation

The Chinle Formation in the vicinity of the HMC Mill site includes three water-bearing horizons. As discussed in Section 2.3.9, the Chinle is a heterogenous formation that is dominated by silty sandstones and contains discontinuous sandstone lenses and silty sandstones. Although three permeable horizons are present beneath the site (described below), they are discontinuous and are not considered regional aquifers (Brod and Stone 1981). However, to be consistent with past site characterizations they are referred to as aquifers in this HSCM.

Upper Chinle. The local extent and subcrop areas of the Upper Chinle aquifer are shown on Figure 46. The Upper Chinle acts as a confined sandstone aquifer bounded above and below by lower-permeability mudstone layers of the Chinle Formation (HDR 2016). The aquifer thickness ranges between 15 and 65 feet with an average of 35 feet near the HMC Mill site (HDR 2016). As previously discussed, vertical displacement at the East Fault has created a lateral discontinuity in the Upper Chinle aquifer (Figure 40). The juxtaposition of the Upper Chinle against the lower-permeability mudstone units along the East Fault presents a barrier to horizontal flow, as evidenced by relatively large groundwater head differences over short horizontal distances across the fault (HDR 2016). Near the southern terminus of the East Fault, groundwater heads on either side of the fault are similar, indicating a lateral hydraulic connection where the fault pinches out (HDR 2016).

Aquifer properties vary significantly in the Upper Chinle aquifer because of fracturing and faulting (HDR 2016). Hydraulic conductivity of the Upper Chinle ranges from 0.1 to more than 100 ft/d (HDR 2016). The highest hydraulic conductivity values occur in a narrow band of fracturing on either side of the East Fault. Transmissivity values in this zone of fracturing have been estimated to range from 13 to more than 1,300 square feet per day (ft^2/d). Estimated aquifer storage parameters for the Upper Chinle have not been reported, but a storage coefficient of 0.0001 was used during groundwater modeling of the site (HDR 2016).

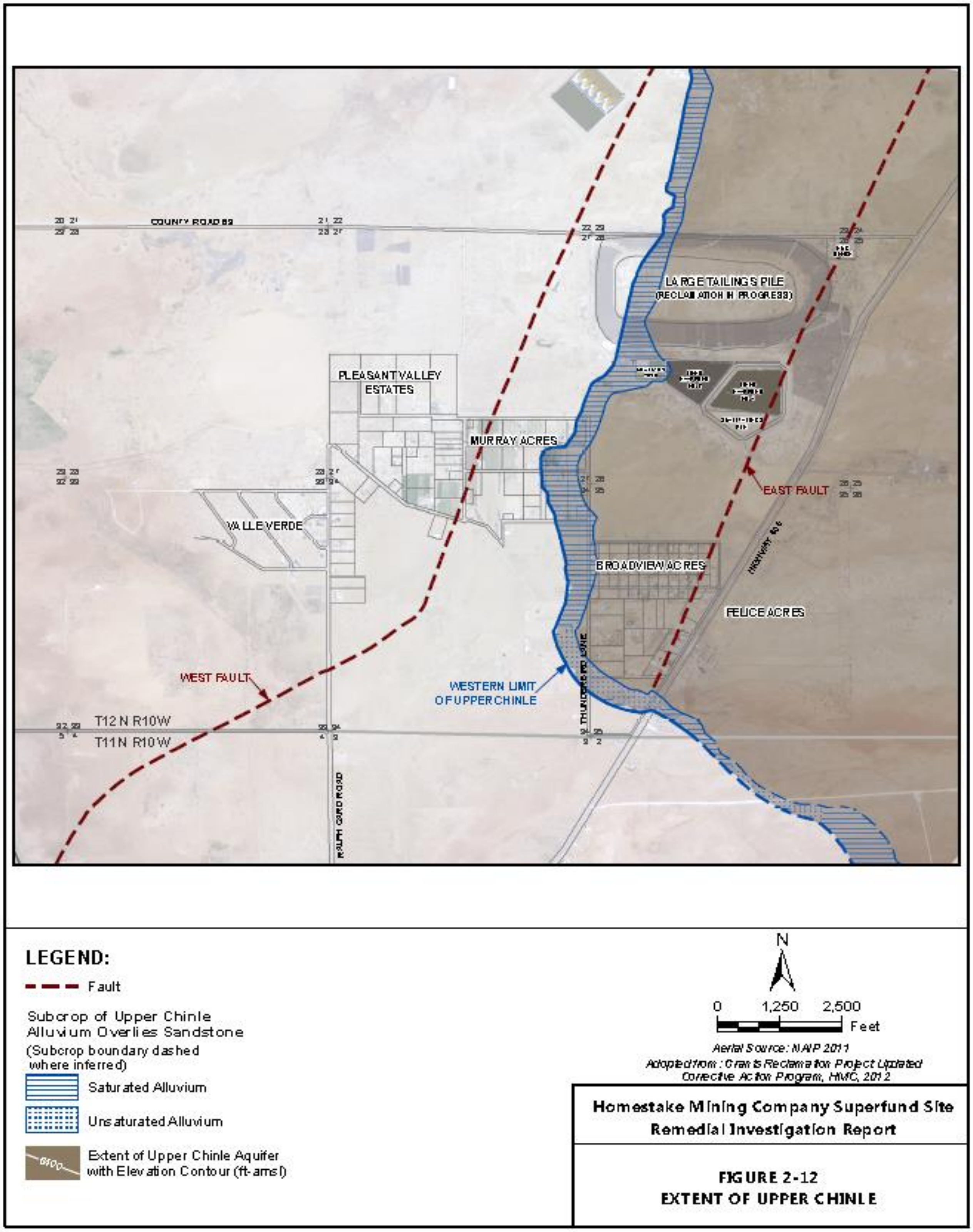


Figure 46. Extent of the Upper Chinle Aquifer

Source: HDR 2016

Middle Chinle. The local extent and subcrop areas of the Middle Chinle aquifer are shown on Figure 47. Like the Upper Chinle, the Middle Chinle acts as a confined sandstone aquifer bounded above and below by lower-permeability mudstone layers of the Chinle Formation (HDR 2016). The aquifer thickness ranges between 10 and 80 feet with an average of 44 feet near the HMC Mill site (HDR 2016). The Middle Chinle exists as three fault-bounded groundwater systems separated by the East and West faults (Figure 40), as evidenced by relatively large groundwater head differences over short horizontal distances across the faults (HDR 2016). Along the West Fault, the subcrop is laterally offset by approximately 5,400 feet because of fault displacement (HDR 2016).

Estimated aquifer conductivity for the Middle Chinle is approximately 25 ft/d, with transmissivities ranging from 67 to 940 ft^2/d (HDR 2016). In addition, transmissivity values ranging from 7 to 2,764 ft^2/d, with typical values of 30 to 300 ft^2/d, and a storage coefficient of 0.0001 were used during groundwater modeling of the site (HDR 2016).

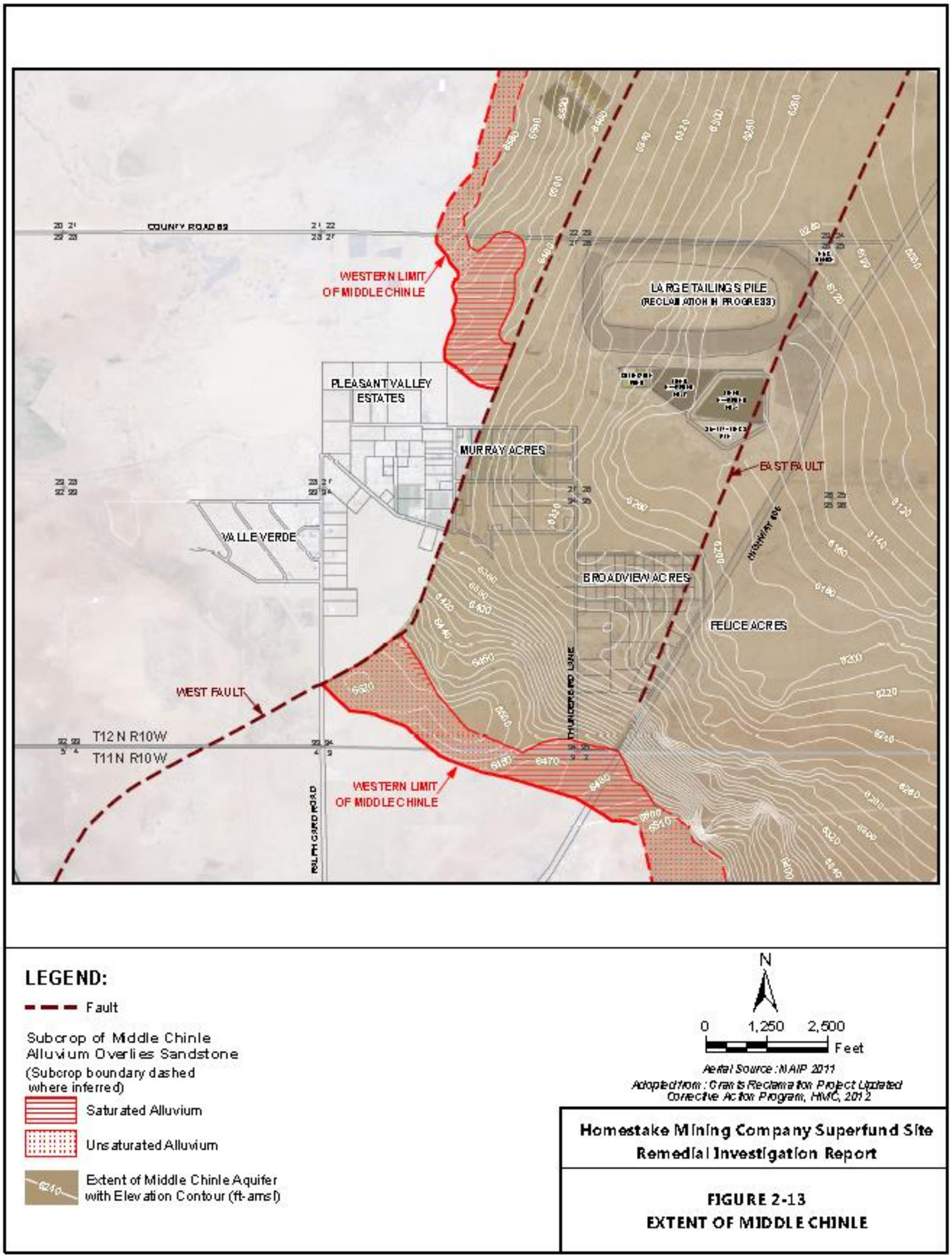


Figure 47. Extent of the Middle Chinle Aquifer

Source: HDR 2016

Lower Chinle. The local extent and subcrop areas of the Lower Chinle aquifer are shown on Figure 48. The Lower Chinle is a horizon of higher-permeability fractured mudstone that acts as a confined aquifer bounded above and below by lower-permeability mudstone layers of the Chinle Formation (HDR 2016). The permeability of the Lower Chinle aquifer is largely derived from fracturing (HDR 2016). The Lower Chinle is located approximately 200 feet above the contact between the Chinle Formation and the San Andres Limestone (HDR 2016). The permeability of the aquifer is not consistently high enough to serve as a viable aquifer, and areas exist where the aquifer is effectively absent. Like the Upper and Middle Chinle aquifers, the Lower Chinle aquifer is fault-bounded into three distinct groundwater systems by the East and West faults (Figure 40) (HDR 2016). Along the West Fault, the subcrop is offset by approximately 3,000 feet laterally because of fault displacement (HDR 2016).

Hydraulic conductivity of the Lower Chinle ranges from 0.1 to more than 50 ft/d (HDR 2016). Transmissivity values are generally greater than 13 ft^2/d near subcrop locations, but can exceed 130 ft^2/d at select locations (HDR 2016). Estimated aquifer storage parameters for the Lower Chinle have not been reported, but a storage coefficient of 0.0001 was used during groundwater modeling of the site (HDR 2016).

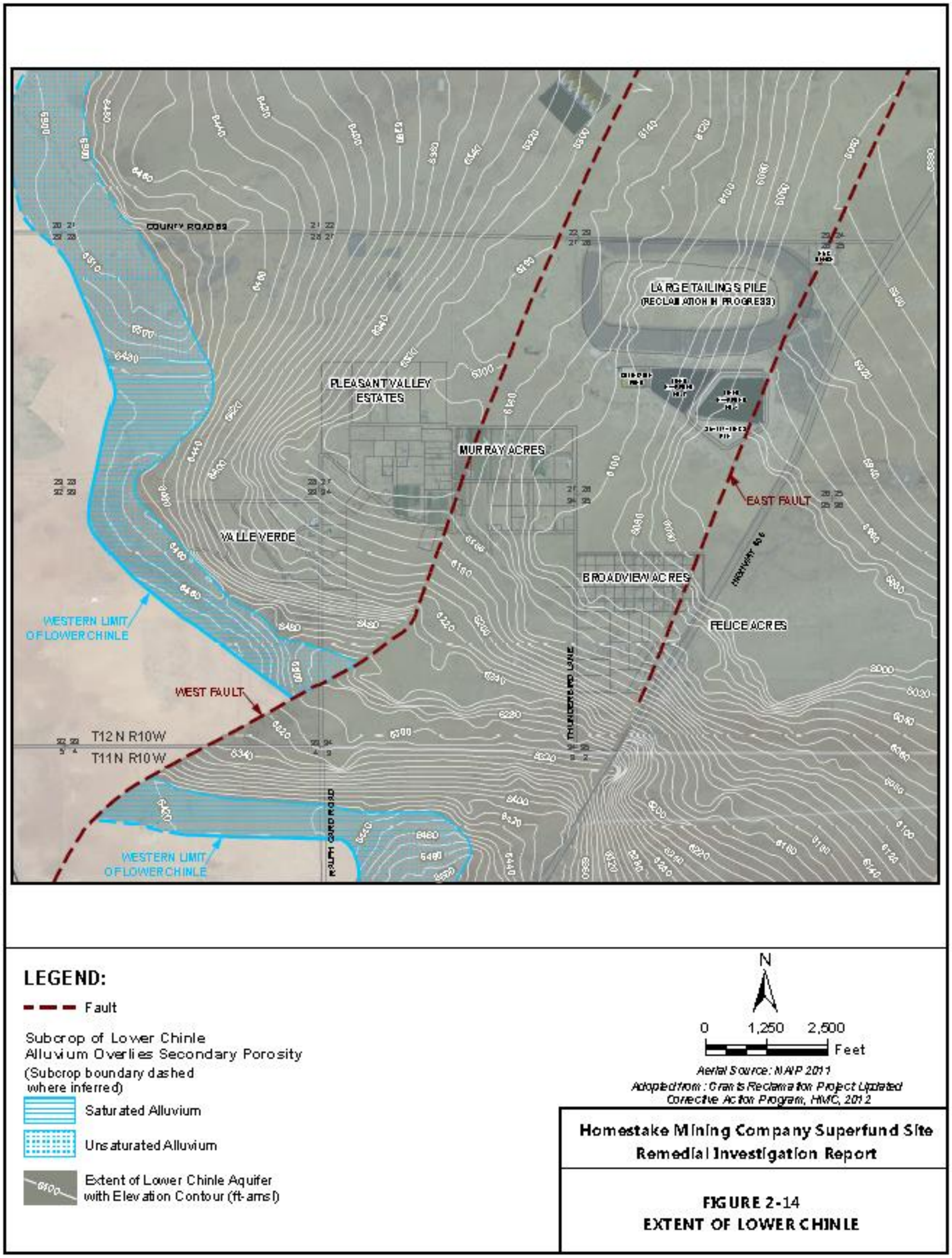


Figure 48. Extent of the Lower Chinle Aquifer

Source: HDR 2016

3.2.3 SAG Aquifer

The local extent and subcrop areas of the SAG aquifer are shown on Figure 49. The SAG aquifer has a thickness exceeding 200 feet near the HMC Mill site and is the significant regional aquifer in the area (HDR 2016). As previously discussed, the East and West faults do not displace the San Andres Limestone and Glorieta Sandstone enough to cause a lateral discontinuity (Figure 40), although the transmissive thickness of the aquifer is likely reduced at the faults because of the displacement (HDR 2016). Relatively flat head gradients across the East and West faults indicate the continuity of the SAG aquifer throughout the site (HDR 2016). The SAG aquifer subcrops west of the West Fault only in the southwestern-most portion of the HMC Mill site.

As previously discussed, groundwater in the SAG aquifer is transmitted in solution channels, cavernous zones, and fractures in the San Andres Limestone. Local estimates of SAG aquifer hydraulic properties are not available at the HMC Mill site. However, HDR (2016) reports an estimated average transmissivity value of 50,000 ft^2/d and a hydraulic conductivity of 615 ft/d based on Baldwin and Anderholm (1992) and Frenzel (1992). Hydraulic conductivity and porosity are likely to vary greatly in the SAG aquifer because of the presence of highly transmissive channels, zones, and fractures (HDR 2016). Estimated aquifer storage parameters for the SAG aquifer at the HMC Mill site have not been reported, but storage coefficients ranging from $5.3x10^{-5}$ to $1.2x10^{-2}$ have been reported at the Bluewater Mill site (U.S. DOE 2014). A storage coefficient of 0.0001 was used during groundwater modeling of the HMC Mill site (HDR 2016).

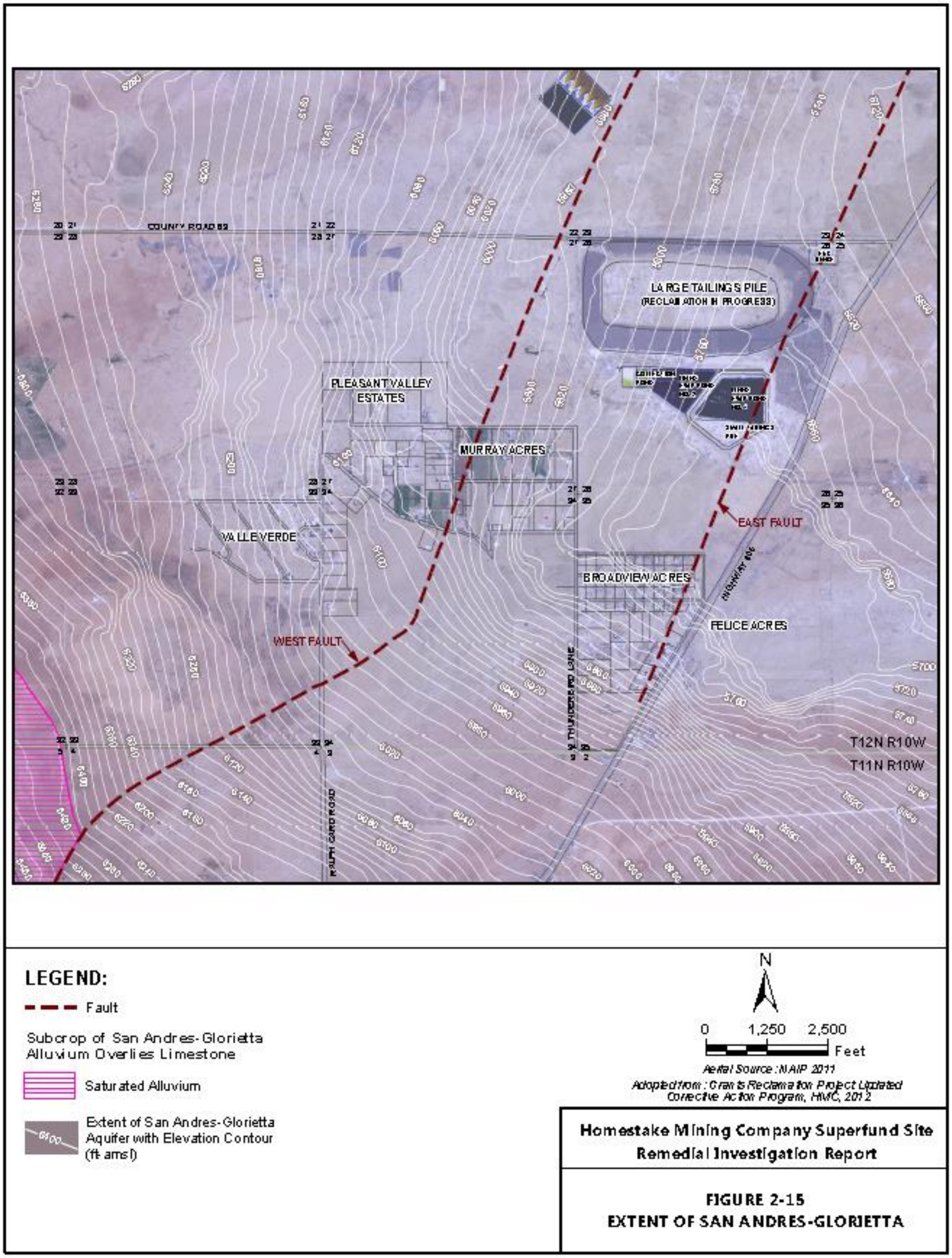


Figure 49. Extent of the SAG Aquifer

Source: HDR 2016

3.3 Site Groundwater Recharge, Discharge, and Flow Directions

Groundwater recharge, discharge, and flow directions at the HMC Mill site are influenced by both natural processes and active remedial operations (i.e., collection and injection). The recharge and discharge sources, flow directions, and interactions between aquifers are discussed below. This section describes groundwater in the following three stratigraphic units at the site:

- Alluvial aquifer
- Chinle Formation
- SAG aquifer

3.3.1 Alluvial Aquifer

The alluvial aquifer at the HMC Mill site is recharged from (1) surface streamflow infiltration losses and precipitation that collects in low-lying areas, (2) continued draindown of the Large Tailings Pile, (3) injection of treated groundwater and SAG groundwater via the site remediation system, and (4) discharge from the underlying Chinle and SAG aquifers at subcrops where heads in these aquifers are higher than alluvial aquifer heads. Discharge from the alluvial aquifer occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the underlying Chinle and SAG aquifers at subcrops where heads in the alluvial aquifer are higher than heads in these aquifers, and (3) groundwater outflow downgradient (south) of the HMC Mill site.

An interpreted potentiometric surface and generalized flow directions for the alluvial aquifer at the HMC Mill site are shown on Figure 50 (based on data collected in fall 2016). At the scale of the site, alluvial groundwater generally flows parallel to the directions of flow of SMC, Rio Lobo, and Rio San Jose. Groundwater approaches the site from the northeast from upgradient areas in the SMC alluvium. After flowing beneath the tailings piles, groundwater flow bifurcates around a local bedrock high into two branches. One branch flows west toward the Rio San Jose alluvium, while the other branch flows south through the Rio Lobo alluvium before turning west through a narrow channel toward the Rio San Jose alluvium. In the Rio San Jose alluvium, groundwater generally flows toward the southeast.

An area of depressed alluvial groundwater levels occurs in the southern portion of the Rio San Jose alluvium. This depression occurs where the San Andres Limestone subcrops beneath the alluvium (Figure 49) and likely represents alluvial discharge to the SAG aquifer because heads in the alluvial aquifer are higher than heads in the SAG aquifer at this location.

The natural flow gradient of the alluvial aquifer is locally affected by collection and injection operations. A hydraulic barrier is maintained immediately downgradient of the tailings piles through injection (HDR 2016), as shown by the potentiometric surface contours and generalized flow directions on Figure 50. Groundwater beneath the tailings piles is collected through a series of collection wells. In other areas of the site, collection and injection wells create localized areas of depression and mounding that are not readily apparent at the 5-foot contour scale of Figure 50.

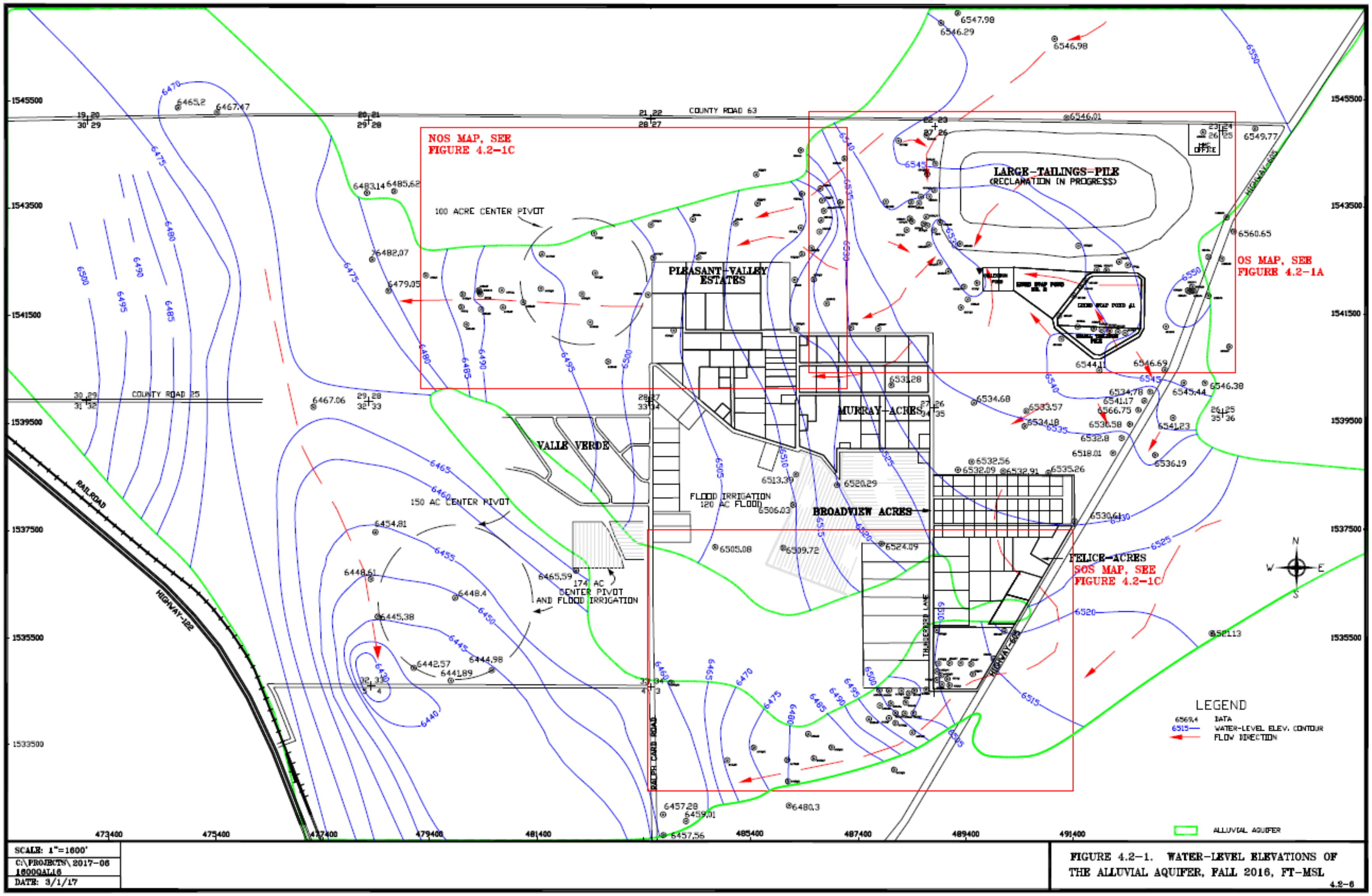


Figure 50. Alluvial Aquifer Groundwater Elevations and Flow Directions

Source: Hydro-Engineering, LLC 2017

3.3.2 Upper Chinle Aquifer

The Upper Chinle aquifer at the HMC Mill site is recharged from (1) injection of treated groundwater and SAG groundwater via the site remediation system operations and (2) recharge from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the Upper Chinle. Discharge from the Upper Chinle aquifer occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the Upper Chinle aquifer are higher than alluvial heads, and (3) groundwater outflow to east-southeast of the HMC Mill site.

Water-level elevations and generalized flow directions for the Upper Chinle aquifer at the HMC Mill site are shown on Figure 51 (based on data collected in fall 2016). The ambient flow direction in the Upper Chinle aquifer between the East and West faults is from north to south (Hydro-Engineering, LLC 2017), but collection and injection operations have affected flow directions in some areas. Groundwater collection and injection south of the Large Tailings Pile has impacted flow directions in the Upper Chinle aquifer. Injection from well CW13 on the east side of the East Fault has caused groundwater mounding in this area.

Groundwater on either side of the East Fault flows parallel to the fault in highly transmissive zones of the Upper Chinle aquifer (Hydro-Engineering, LLC 2017). Groundwater flow across the fault is significantly restricted by vertical offsetting of the aquifer. Near the Large Tailings Pile, alluvial groundwater recharges the Upper Chinle aquifer through subcrops. The Upper Chinle aquifer discharges groundwater back into the alluvium through subcrops in the southern portions of the site (e.g., near Felice Acres) (Hydro-Engineering, LLC 2017).

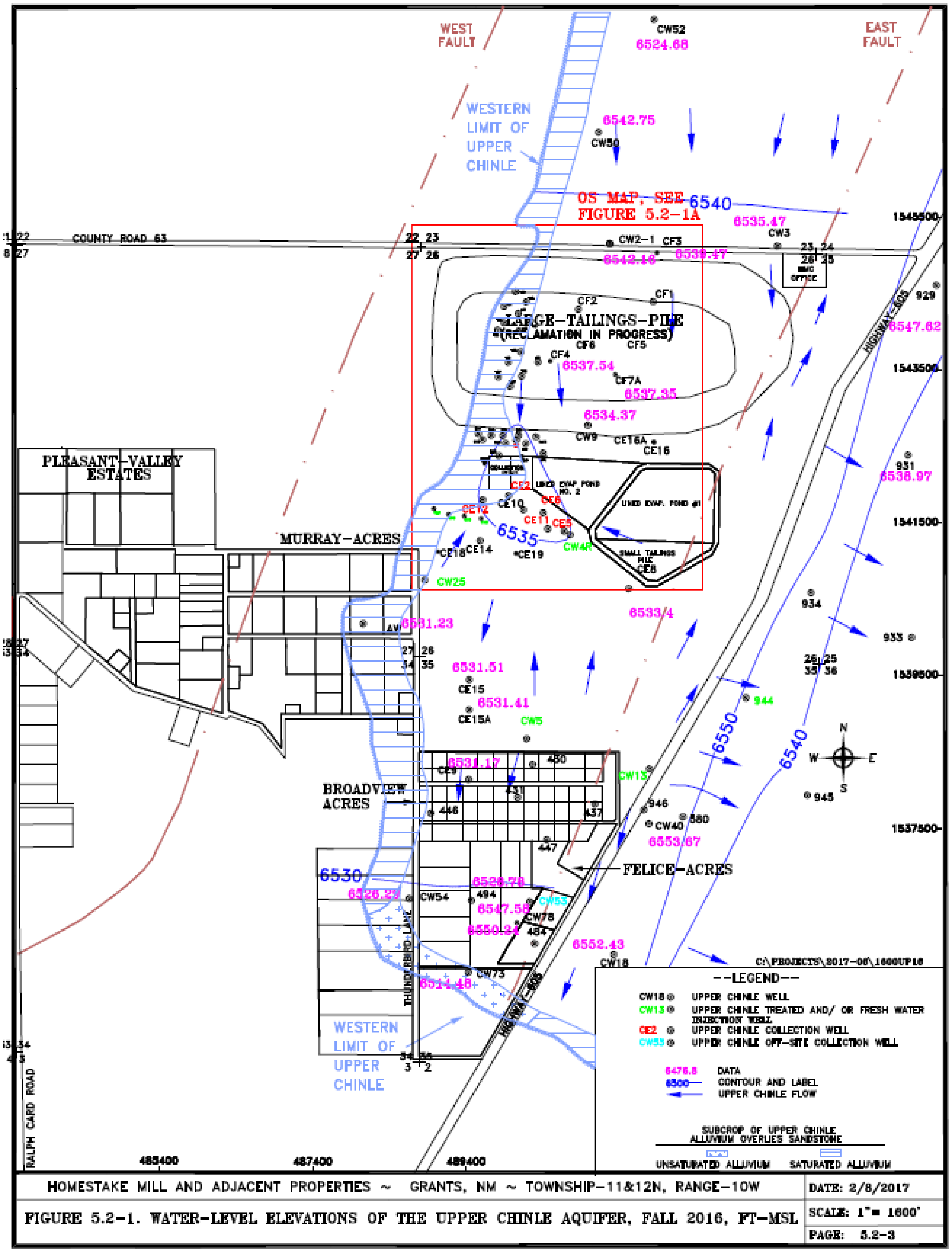


Figure 51. Upper Chinle Aquifer Groundwater Elevations and Flow Directions

Source: Hydro-Engineering, LLC 2017

3.3.3 Middle Chinle Aquifer

The Middle Chinle aquifer at the HMC Mill site is recharged from (1) injection of treated groundwater and SAG groundwater via the site remediation system operations and (2) recharge from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the Middle Chinle. Discharge from the Middle Chinle aquifer occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the Middle Chinle aquifer are higher than alluvial heads, and (3) groundwater outflow to the east-southeast of the HMC Mill site.

Water-level elevations and flow direction arrows for the Middle Chinle aquifer at the HMC Mill site are shown on Figure 52 (based on data collected in fall 2016). The ambient flow direction in the Middle Chinle aquifer appears to be from the north to south: (1) west of the West Fault and (2) between the East and West faults. East of the East Fault, the gradient is lower and the ambient flow direction is difficult to discern in the presence of collection and injection. Vertical offset of the Middle Chinle aquifer at the East and West faults restricts groundwater flow across the faults, as evidenced by large head differences across the faults (HDR 2016). Groundwater collection and injection activities near the Middle Chinle subcrops have created localized areas of depression and mounding.

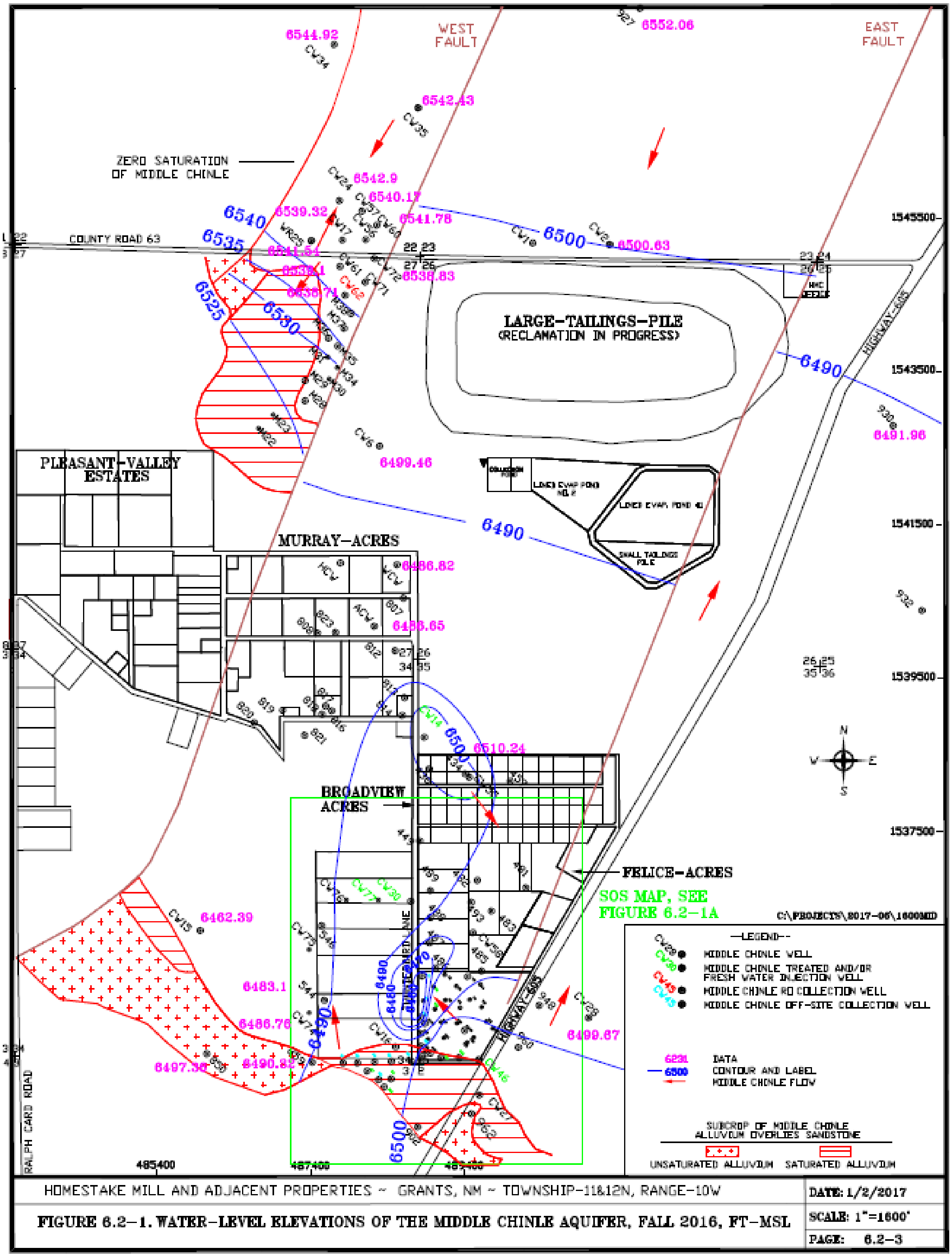


Figure 52. Middle Chinle Aquifer Groundwater Elevations and Flow Directions

Source: Hydro-Engineering, LLC 2017

3.3.4 Lower Chinle Aquifer

The Lower Chinle aquifer at the HMC Mill site is recharged from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the Lower Chinle. Injection from the site remediation system is not occurring in the Lower Chinle. Discharge from the Lower Chinle aquifer occurs via (1) pumping of contaminated groundwater to the treatment plants, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the Lower Chinle aquifer are higher than alluvial heads, and (3) groundwater outflow to the north-northeast of the HMC Mill site.

Water-level elevations and generalized flow directions for the Lower Chinle aquifer at the HMC Mill site are shown on Figure 53 (based on data collected in fall 2016). The ambient flow direction in the Lower Chinle appears to be away from the subcrop locations, where alluvial groundwater recharges the Lower Chinle. This results in a generally northeast flow direction beneath the site. Limited groundwater collection (only one well in 2016) has not significantly affected groundwater flow directions.

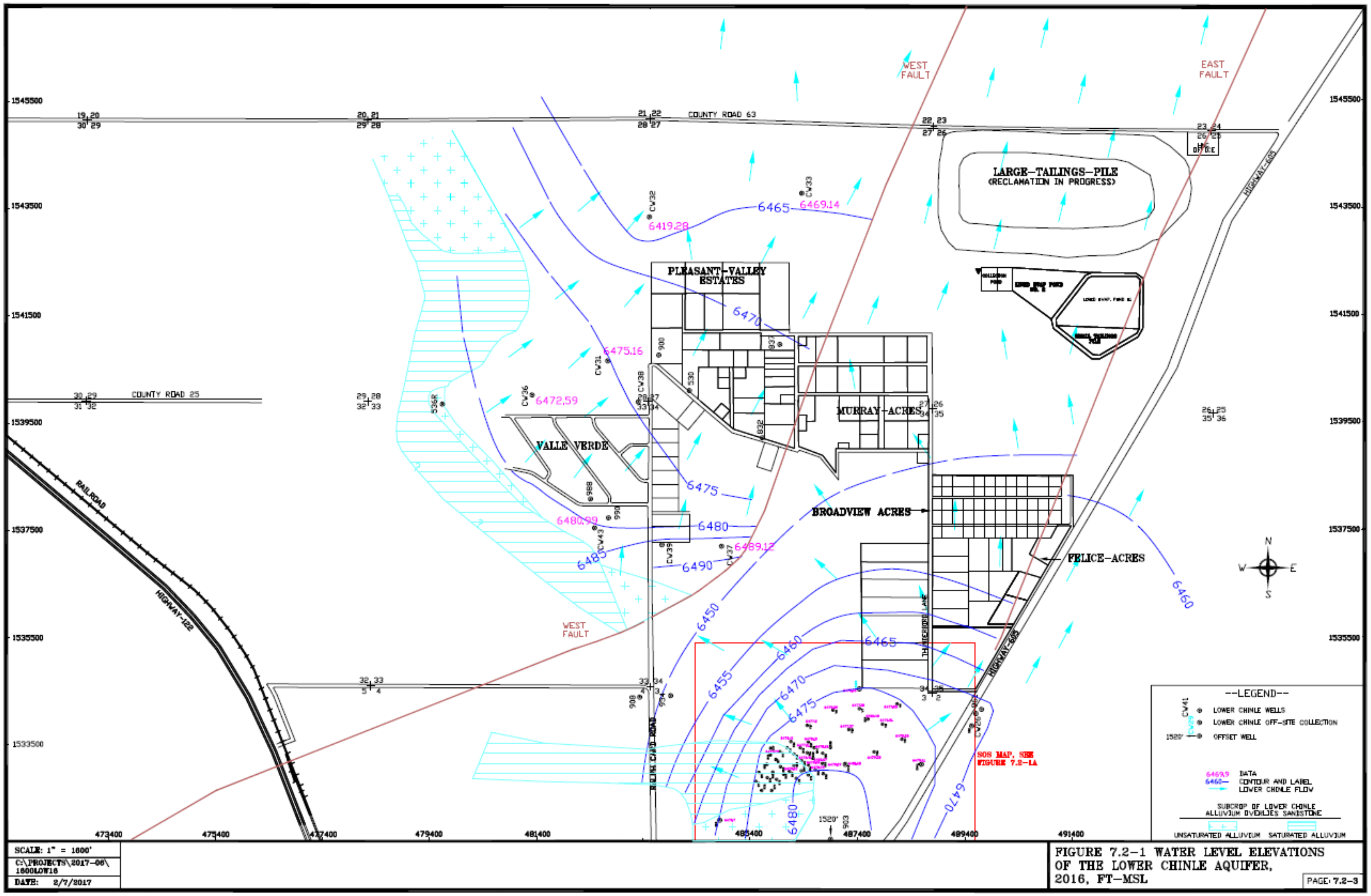


Figure 53. Lower Chinle Aquifer Water Levels and Flow Directions

Source: Hydro-Engineering, LLC 2017

3.3.5 SAG Aquifer

The SAG aquifer at the HMC Mill site is recharged from the overlying alluvial aquifer at subcrops where alluvial heads are greater than heads in the SAG. Injection from the site remediation system is not occurring in the SAG. Discharge from the SAG aquifer occurs via (1) pumping of groundwater as a source of fresh water for use in the treatment plants' hydraulic containment system in the alluvial and Chinle aquifers, (2) discharge to the overlying alluvial aquifer at subcrops where heads in the SAG aquifer are higher than alluvial heads, and (3) groundwater outflow to the east-southeast. In the vicinity of the site, the primary interaction between the SAG and alluvial aquifers appears to be recharge of the SAG aquifer from the overlying alluvium, as evidenced by higher alluvial heads compared to SAG heads near the SAG subcrop.

Water-level elevations and generalized flow directions for the SAG aquifer at the HMC Mill site in fall 2016 are shown on Figure 54. The ambient flow direction in the SAG aquifer is to the east-southeast. The hydraulic gradient is relatively flat compared to the gradients in the overlying alluvial and Chinle aquifers.

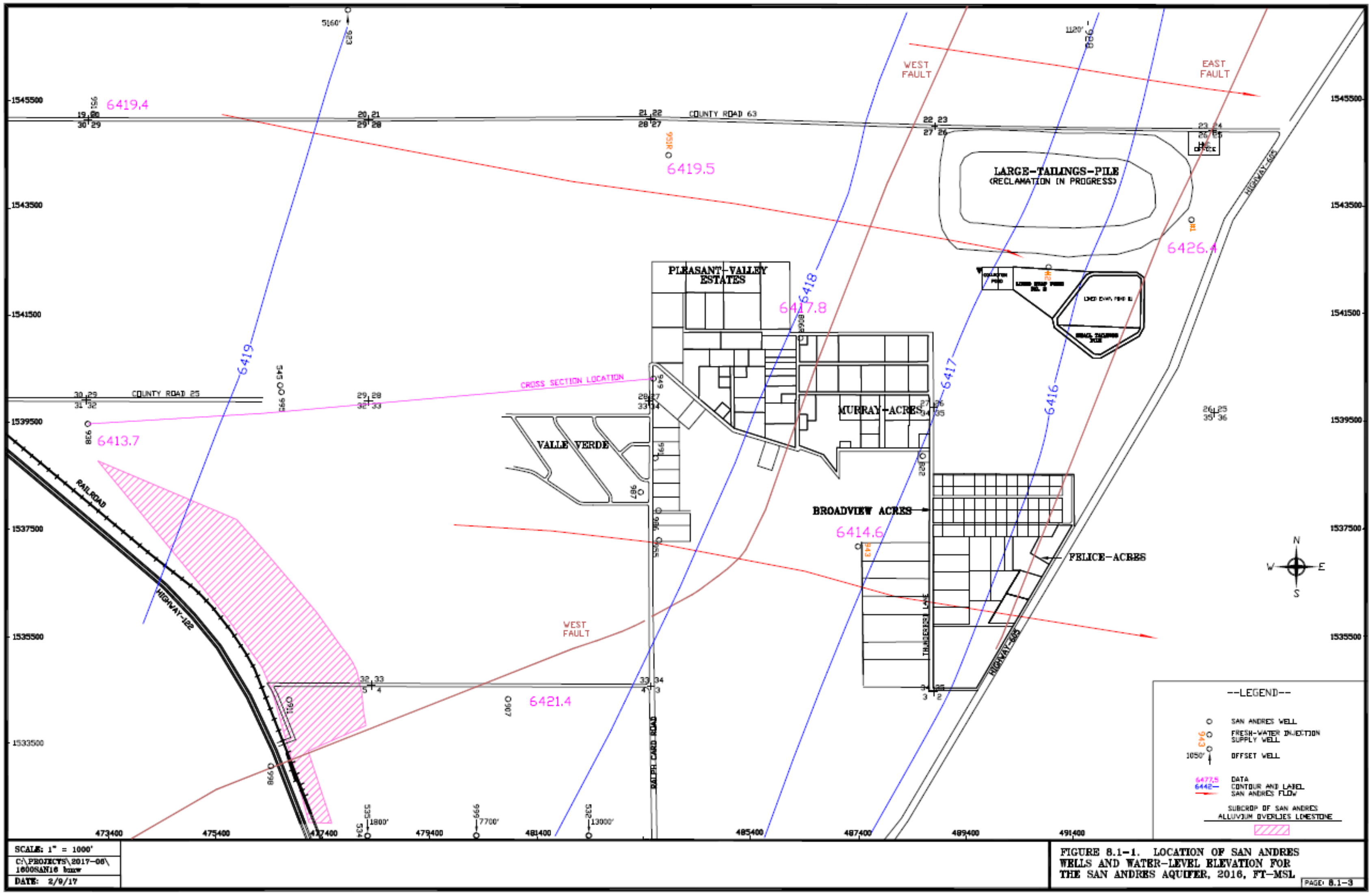


Figure 54. SAG Aquifer Groundwater Elevations and Flow Directions

Source: Hydro-Engineering, LLC 2017

3.4 Extent of Contaminated Groundwater

This section presents a summary of the extent of groundwater impacted from the HMC Mill site, including nearby offsite locations.

3.4.1 Contamination from the HMC Mill

The primary sources of groundwater contamination at the HMC Mill site are the Large and Small tailings piles (HDR 2016). Historical seepage of process-water-bearing uranium and other trace radioactive and non-radioactive constituents resulted in loading of these metals to alluvial groundwater beneath the tailings piles. The extent of contamination in the alluvial and Chinle aquifers at the end of 2016, based on uranium concentrations exceeding the current site standards (NRC License Cleanup levels, as discussed in HDR 2016), is shown on Figures 55 through 58. Groundwater contamination from the HMC Mill site has not been detected in the SAG aquifer. Substantial progress in reducing constituent concentrations has been made in the alluvial and Chinle water-bearing zones since remediation activities began in the 1980s.

In the alluvial aquifer, groundwater concentrations exceed uranium site standards (1) beneath the tailings piles, (2) in western and southern plumes emanating from the tailings pile area, and (3) in an apparently isolated plume south of Felice Acres (Figure 55).

In the Upper Chinle aquifer, groundwater concentrations exceed the uranium site standards (1) beneath the tailings piles and (2) near Broadview and Felice Acres (Figure 56).

In the Middle Chinle aquifer, groundwater concentrations exceed uranium site standards (1) near the subcrop west of the West Fault and (2) near Broadview and Felice Acres (Figure 57).

In the Lower Chinle aquifer, groundwater concentrations exceed uranium site standards near the subcrop south of Felice Acres (Figure 58).

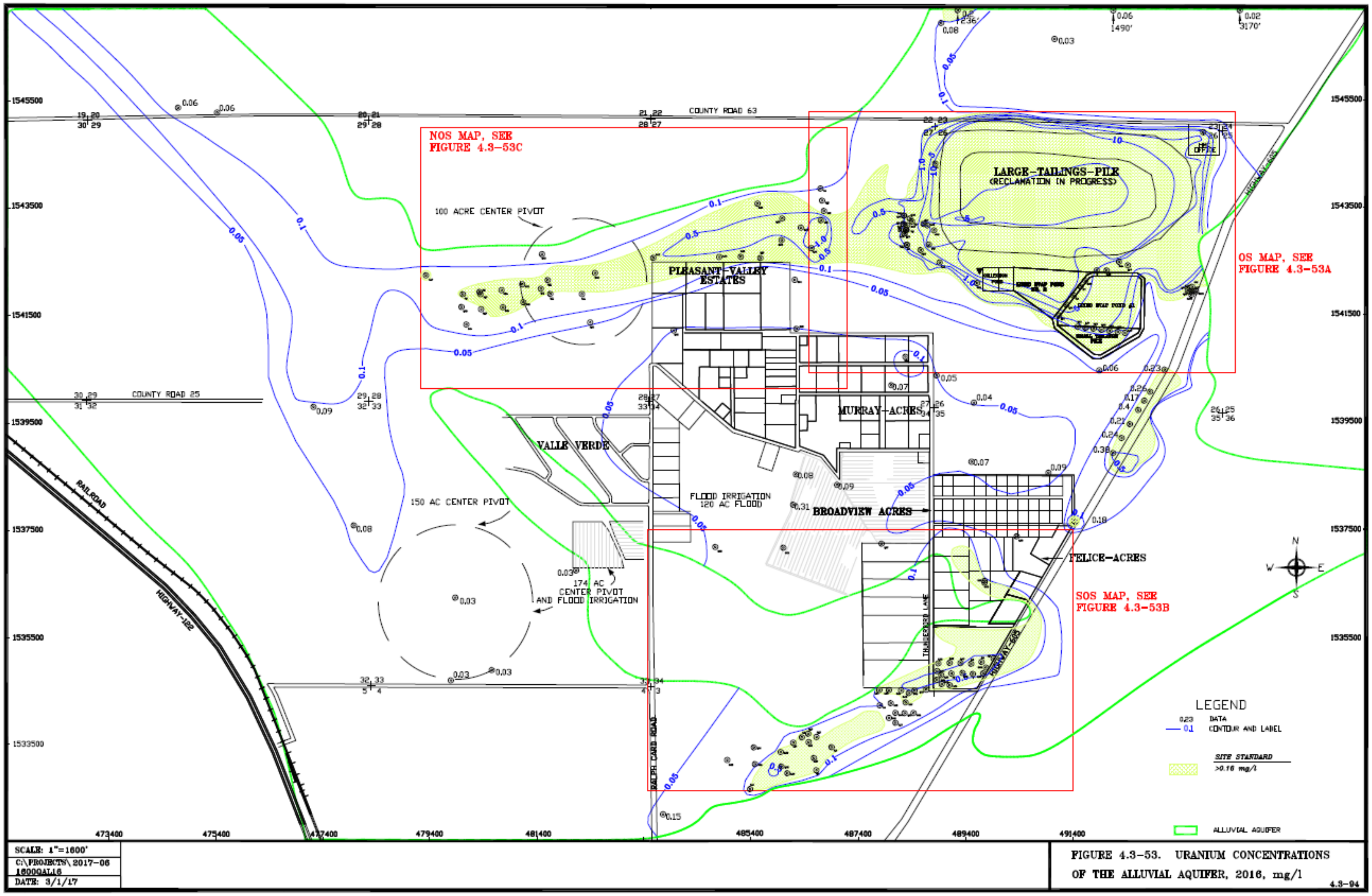


Figure 55. Extent of Uranium Contamination in the Alluvial Aquifer

Source: Hydro-Engineering, LLC 2017

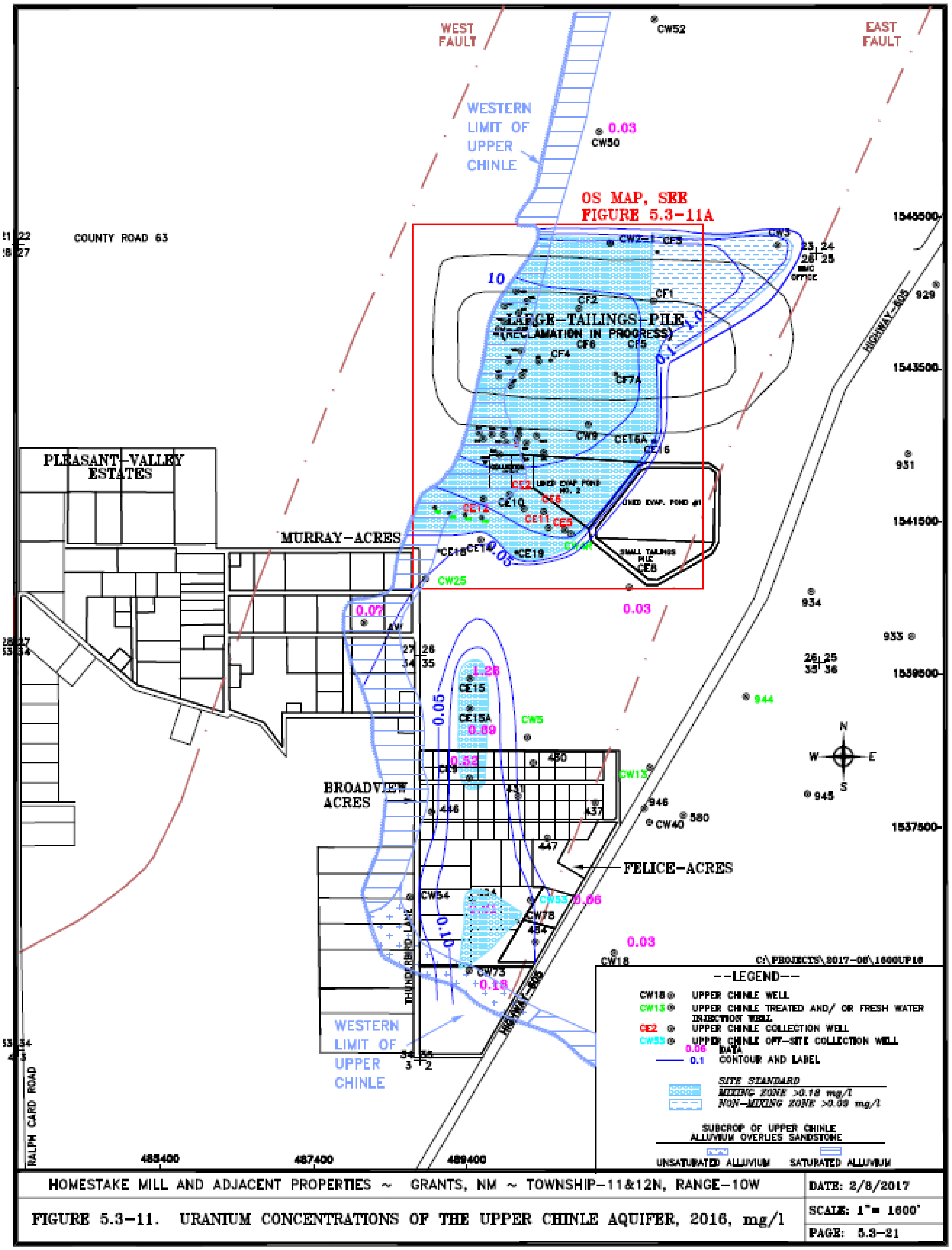


Figure 56. Extent of Uranium Contamination in the Upper Chinle Aquifer

Source: Hydro-Engineering, LLC 2017

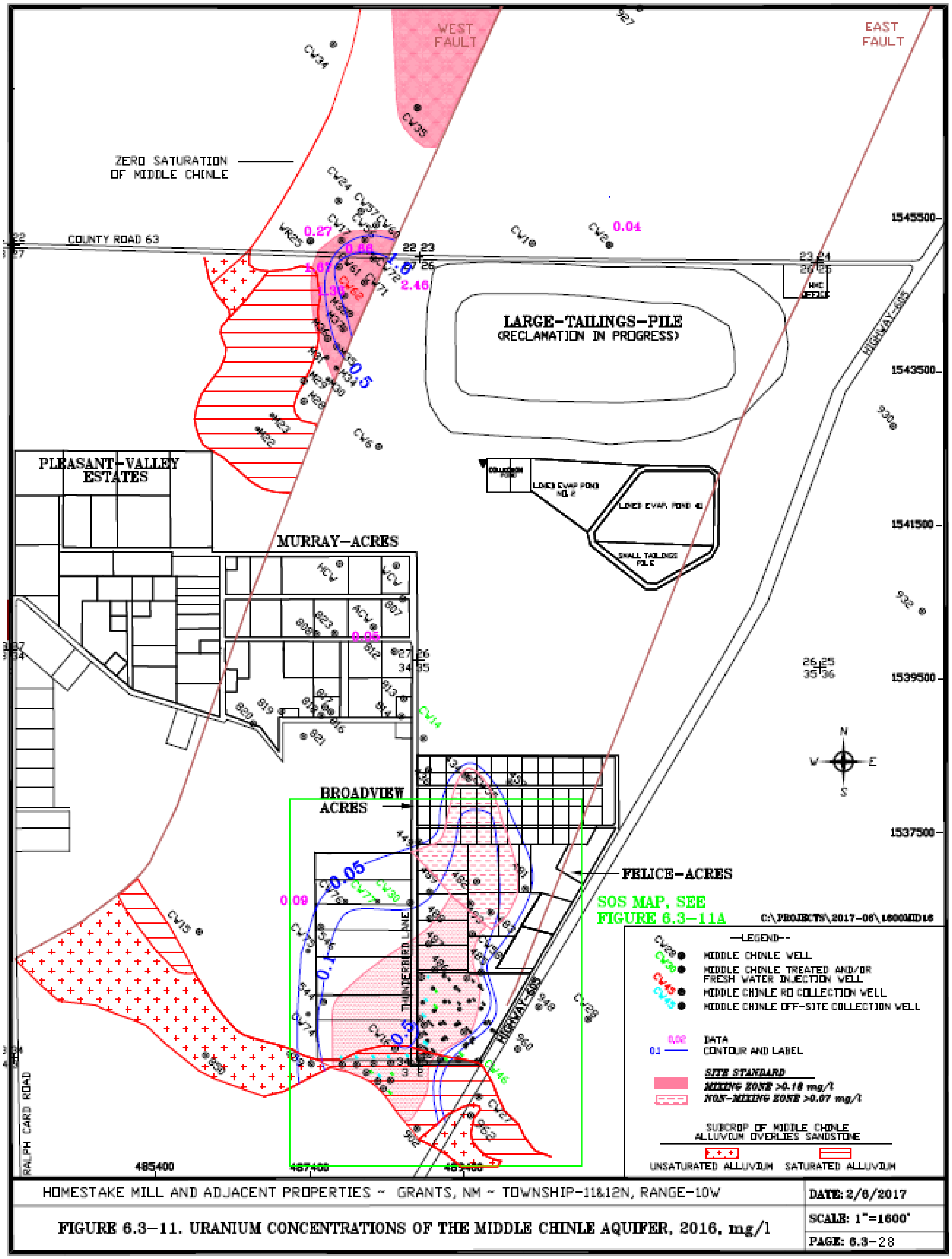


Figure 57. Extent of Uranium Contamination in the Middle Chinle Aquifer

Source: Hydro-Engineering, LLC 2017

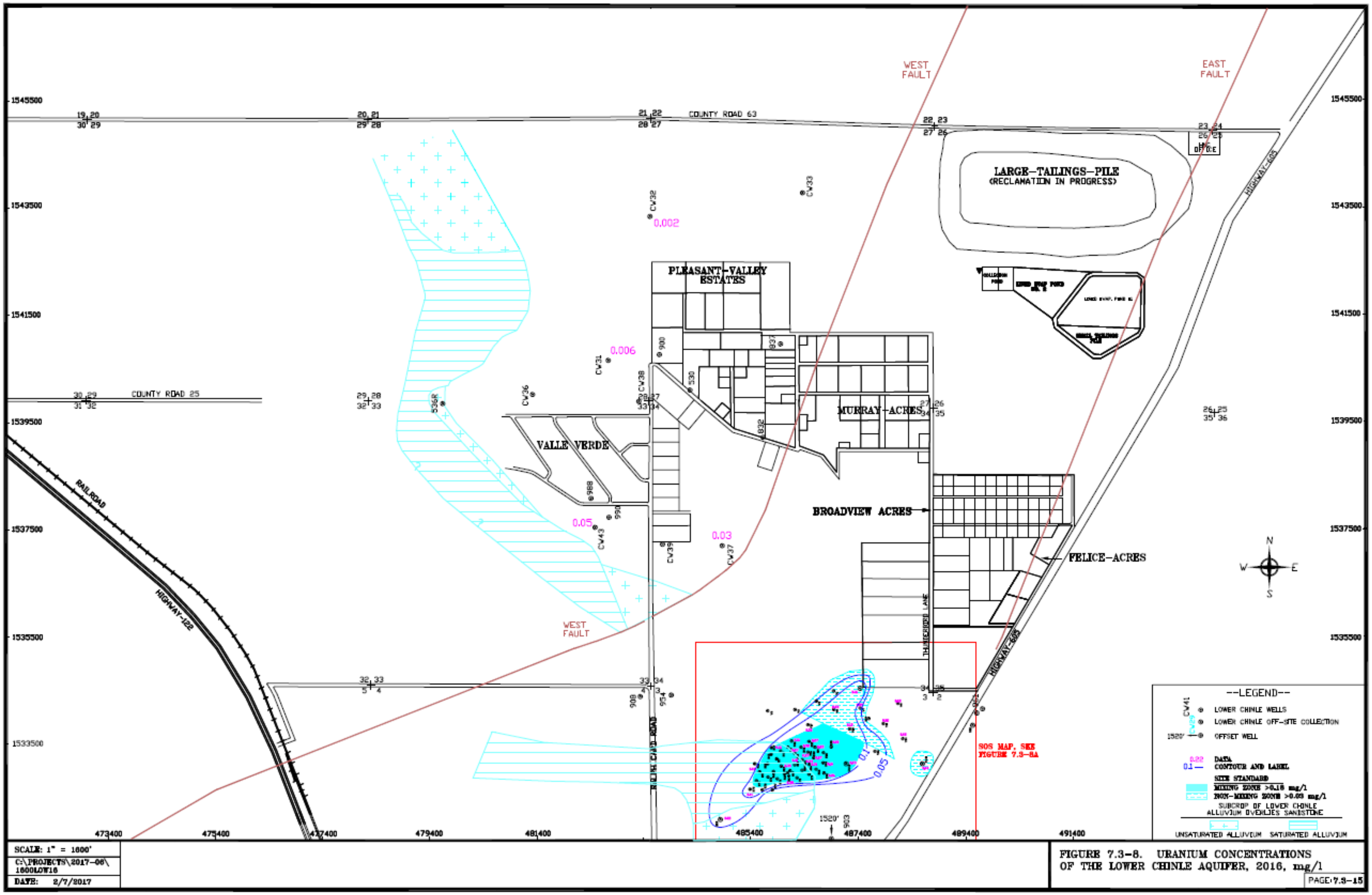


Figure 58. Extent of Uranium Contamination in the Lower Chinle Aquifer

Source: Hydro-Engineering, LLC 2017

3.4.2 Contamination from Offsite Locations

Figure 59 presents time series of selenium concentrations in several alluvial monitoring wells including wells Q and R, which are located in the SMC alluvium approximately 0.5 mile and 1.0 mile upgradient of the HMC Mill site, respectively. Concentrations in these wells exceed the selenium site standard of 0.32 milligram per liter (mg/L). These elevated selenium concentrations have been interpreted as representing contamination from the slow migration of mine dewatering and process water discharged to surface drainages and alluvium upgradient of the site in the SMC Basin. Movement of this groundwater was previously discussed in Section 3.4.2.

Figure 60 presents iso-concentration contours of uranium in the SAG aquifer in the Grants-Bluewater area. Although contamination from the HMC Mill site is not present in the SAG aquifer, a uranium plume is emanating from the upgradient Bluewater Mill site and has increased uranium concentrations in the SAG aquifer near the HMC Mill site. U.S. DOE (2014) characterized this uranium plume as potentially stable since the 1980s based on dilution of a continuous source due to the effects of transverse dispersion.

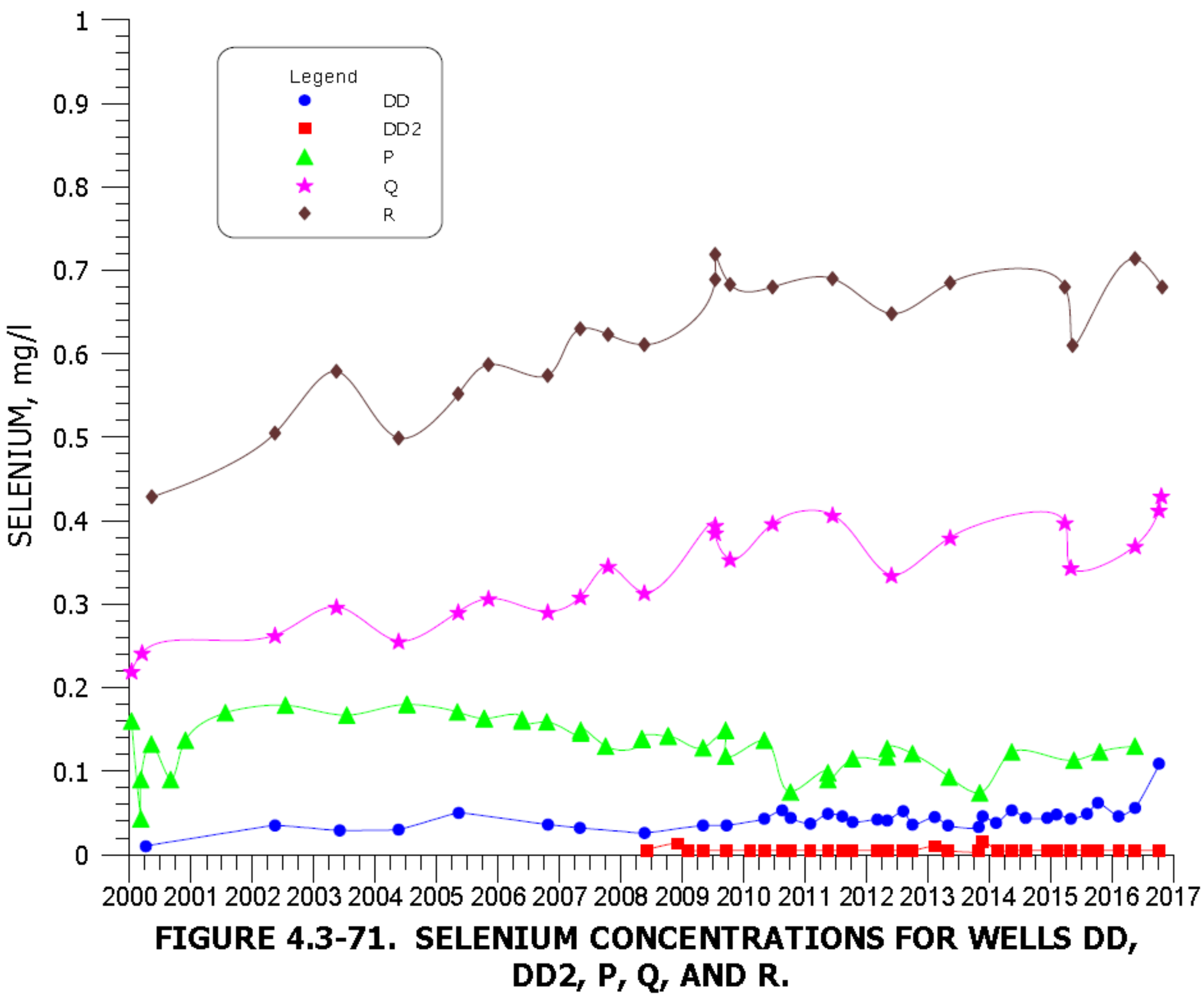


Figure 59. Selenium Concentrations in Upgradient Alluvial Wells

Source: Hydro-Engineering, LLC 2017

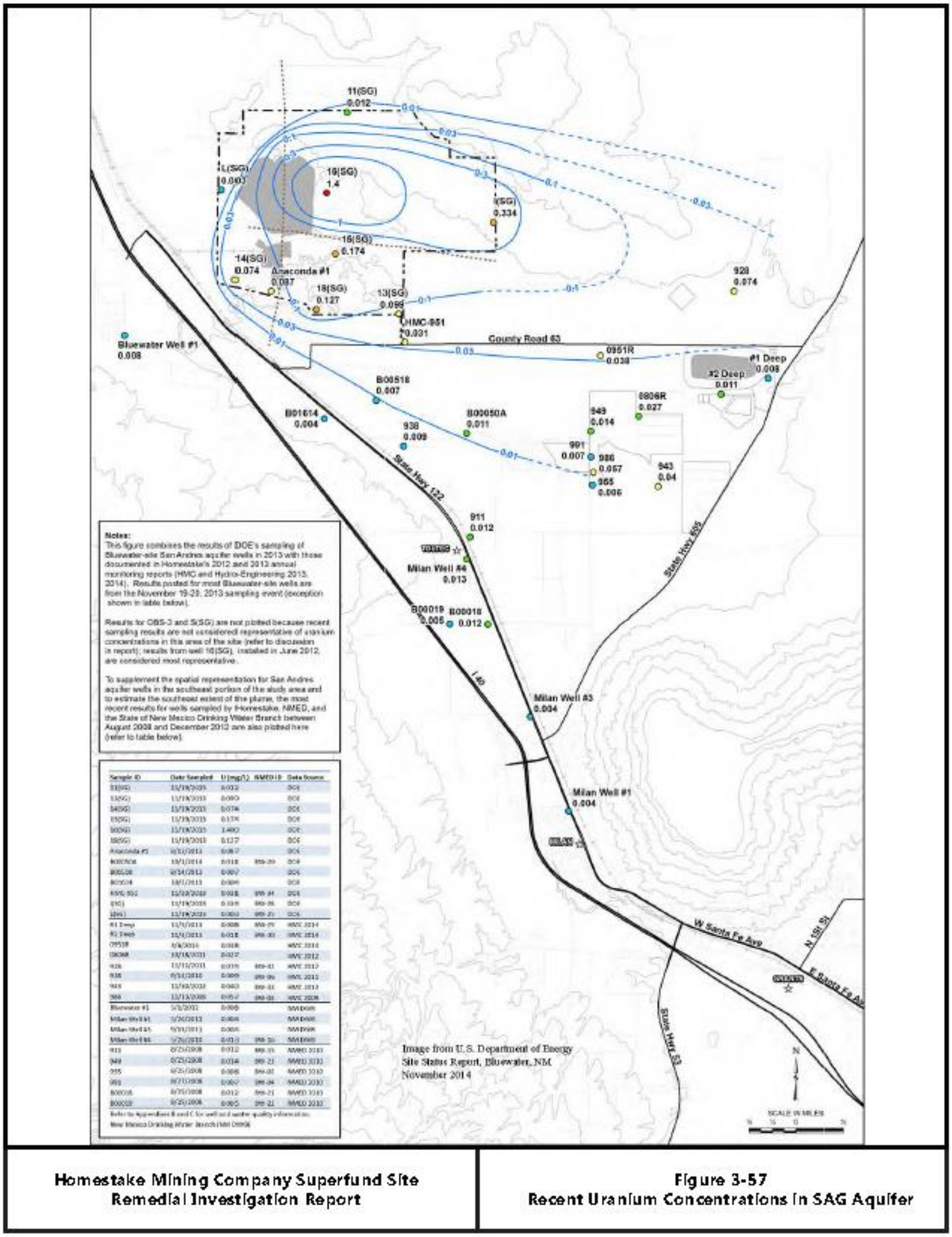


Figure 60. Regional Uranium Concentrations in the SAG Aquifer

Source: Hydro-Engineering, LLC 2017

3.5 Site HSCM Summary

Key elements of the Site HSCM are summarized as follows:

- The HMC Mill site is located in the southern lower portion of the SMC Basin.
- Aquifers of Quaternary, Triassic, and Permian age are present at the site.
- Principal aquifers that include groundwater flow at the site include the alluvium; upper, middle, and lower transmissive units of the Chinle Formation; and SAG aquifer.
- Local groundwater flow in the alluvium generally flows parallel to downgradient surface flows in SMC, Rio Lobo, and Rio San Jose, but bifurcates around a bedrock high.
- Groundwater flow in the Chinle Formation aquifer units and underlying SAG aquifer is generally to the east-southeast.
- Site remedial activities have included groundwater extraction and injection in both the alluvial and Chinle sandstones, affecting local groundwater flow conditions.
- The presence of the East and West fault zones has restricted and redirected local groundwater flow, including in the vicinity of the Large Tailings Pile.
- Local groundwater flow conditions have been well characterized through data collected from hundreds of monitoring wells.

Section 4: Summary

The descriptions of the Regional and Site HSCMs provided here are the culmination of BC's review of available background information related to local and regional geology and hydrogeology in the SMC Basin. The data and descriptions of geologic conditions, principal aquifer units, locations and mechanisms of groundwater recharge and discharge, groundwater flow directions and hydraulic gradients, and aquifer physical parameters will form the basis for numerical model development at both the regional and site scales. BC will provide a detailed plan for numerical model development as part of the next phase of support for developing flow and transport models for the SMC Basin and the HMC Mill site.

References

Baldwin, J.A., and Anderholm, S.K. 1992. Hydrogeology and ground-water chemistry of the San Andres/Glorieta aquifer in the Acoma embayment and eastern Zuni uplift, west-central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 91-4033, 304 p.

Brod, R.C., and Stone, W.J. 1981. Hydrogeology of Ambrosia Lake–San Mateo area, McKinley and Cibola Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, HS–2, text and map, scale 1:62,500.

Cather, S. 2010. Geologic map of the San Lucas Dam quadrangle, McKinley County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 219, map.

Cather, S. 2011. Geologic map of the Dos Lomas quadrangle, Cibola and McKinley Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 212, map.

Ferguson, C. and McCraw, D. 2010. Geologic map of the Ambrosia Lake 7.5-minute quadrangle, McKinley County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 203, map.

Frenzel, P.F. 1983. Simulated changes in ground-water levels related to proposed development of federal coal leases, San Juan Basin, New Mexico: U.S. Geological Survey Open-File Report 83-949, 63 p.

Frenzel, P.F. 1992. Simulation of ground-water flow in the San Andres-Glorieta aquifer in the Acoma embayment and eastern Zuni uplift, west-central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 91-4099, 381 p.

Frenzel, P.F., and Lyford, P.P. 1982. Estimates of vertical hydraulic conductivity and regional ground-water flow rates in rocks of Jurassic and Cretaceous age, San Juan Basin, New Mexico and Colorado: U.S. Geological Survey Water-Resources Investigations Report 82-4015, 59 p.

Goff, F., Kelley, S.A., Zeigler, K., Drakos, P.G., and Goff, C.J. 2008. Geologic map of the Lobo Springs quadrangle, Cibola County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 224, map.

HDR. 2016. Draft remedial investigation report, Homestake Mining Company Superfund Site; variously paged, June.

Homestake Mining Company (HMC). 2017. Site Water Level Database Provided to Brown and Caldwell.

Hydro-Engineering, LLC. 2017. 2016 Annual monitoring report/performance review for Homestake's Grants Project pursuant to NRC License SUA-1471 and Discharge Plan DP-200: prepared for U.S. Nuclear Regulatory Commission and New Mexico Environment Department, variously paged, March.

Langman, J.B., Sprague, J.E., and Durall, R.A. 2012. Geologic framework, regional aquifer properties (1940s–2009), and spring, creek, and seep properties (2009–10) of the upper San Mateo Creek Basin near Mount Taylor, New Mexico: U.S. Geological Survey Scientific Investigations Report 2012-5019, 96 p.

Maxim Technologies, Inc. 2000. Groundwater modeling and feasibility analysis for the application of alternate concentration limits, Quivira Mill Site, Ambrosia Lake, New Mexico: prepared for Quivira Mining Company/Rio Algom, 32 p., July.

McCraw, D.J., Read, A.S., Lawrence, J.R., Goff, F., and Goff, C.J. 2009. Geologic map of the San Mateo quadrangle, McKinley and Cibola Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 194, map.

New Mexico Office of Natural Resources Trustee (NMONRT). 2010. Preassessment Screen and Determination: Rio Algom Mines and Quivira Mill Site, McKinley County, New Mexico; variously paged, September.

Rawling, G. 2012. Geologic map of the Milan quadrangle, Cibola County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 231, map.

Rawling, G.C. 2013a. Geologic map of the Bluewater quadrangle, Cibola and McKinley Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 236, map.

Rawling, G.C. 2013b. Geologic map of the Goat Mountain quadrangle, McKinley County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 240, map.

Stone, W.J., Lyford, F.P., Frenzel, P.F., Mizell, N.H., and Padgett, E.T. 1983. Hydrogeology and water resources of San Juan Basin, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources, Hydrologic Report 6, 70 p.

United States Department of Energy (U.S. DOE). 1996. Long-term surveillance plan for the Ambrosia Lake, New Mexico, Disposal Site: Office of Scientific and Technical Information DOE/AL/62350-211 Rev. 1, variously paged, July.

U.S. DOE. 1997. Long-term surveillance plan for the DOE Bluewater (UMTRCA Title II) Disposal Site Near Grants, New Mexico: U.S. DOE Grand Junction Office Doc. No. S00012AA, 47p., July.

U.S. DOE. 2014. Site status report: groundwater flow and contaminant transport in the vicinity of the Bluewater, New Mexico, Disposal Site: U.S. DOE Legacy Management Doc. No. S11381, 56 p., November.

Weston Solutions, Inc. 2016. Expanded Site Inspection Phase 1: Groundwater investigation report for San Mateo Creek Basin Legacy Site, Cibola and McKinley Counties, New Mexico: Prepared for the U.S. Environmental Protection Agency Region 6, Contract No. EP-W-06-042.

Zeigler, K.E., Cikoski, C.T., Drakos, P.G., and Riesterer, J. 2012. Geologic map of the Grants quadrangle, Cibola County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Digital Geologic Map OF–GM 224, map.